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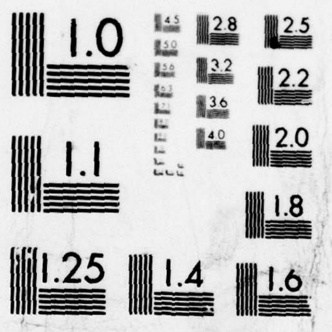

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Operation UPSHOT-KNOTHOL

NEVADA PROVING GROUNDS

March - June 1953

Project 27.2

**ENVIRONMENTAL AND BIOLOGICAL FATE OF FALL-
FROM NUCLEAR DETONATIONS IN AREAS ADJACENT
THE NEVADA PROVING GROUNDS**

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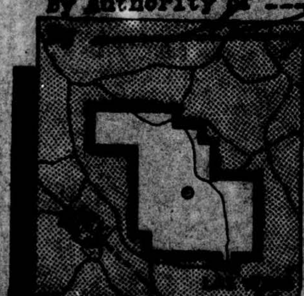

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Report to the Test Director

ENVIRONMENTAL AND BIOLOGICAL FATE OF FALL-OUT FROM NUCLEAR DETONATIONS IN AREAS ADJACENT TO THE NEVADA PROVING GROUNDS

By

Robert G. Lindberg, James T. Scanlan, James C. Watson,
William A. Rhoads, and Kermit H. Larson

Approved by: KERMIT H. LARSON
Director, Program 27

Approved by: ROBERT L. CORSBIE
Director
Civil Effects Test Group

University of California at Los Angeles
School of Medicine
Atomic Energy Project
Los Angeles, California

February 1954

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ABSTRACT

A radio-ecological survey of the area adjacent to Nevada Proving Grounds has been in progress intermittently from September 1951 to July 1953. Samples have been taken periodically of native soils, plants, and animals before, during, and after various test series at distances up to 30 miles from respective Ground Zeros. Data suggest that microcurie levels of radioactive fall-out are potentially available for absorption and/or metabolism by grazing animals at distances at least 15 miles from Ground Zero during the 24 hr following a detonation. The persistence of absorbed radioactive materials in rodent populations, as compared to the radioactive content of their isolated tissues, suggests that absorption is primarily a result of physical diffusion of available ions rather than actual metabolic selection and retention of the mixed fission products ingested or inhaled. Absorbed radioactive materials, therefore, appear to be in equilibrium with certain components of residual environmental contamination during the 90 days following a detonation.

In areas repeatedly contaminated by radioactive fall-out during a two-year period, approximately 90 per cent of the residual radioactive material is associated with the surface inch of soil, indicating that radioactive fall-out continues to be a surface phenomenon in the areas studied, even after exposure of up to two years in a natural semi-arid environment.

The amount of radioactive materials in jack-rabbit femurs and livers has increased threefold over values established in September 1951 prior to any radioactive contamination of the study areas. The amount of radioactive materials associated with washed plant samples is approximately twice the values established in 1951.

Inhalation as a path of uptake fails to account for the major portion of absorbed radioactive materials in rodents and rabbits. Absorbed radioactive material is more completely accounted for through ingestion of primary radioactive fall-out.

Native rodents are suggested as reliable indicators of the biological availability of radioactive materials.

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ACKNOWLEDGMENTS

A project of this scope and duration owes its success to the cooperation of many persons both in the field and in the laboratory and to the generous sharing of many facilities. Although the personnel concerned in obtaining the invaluable data prior to March 1953 must not be overlooked, special acknowledgments are due the groups contributing to the participation of Project 27.2 in Operation Upshot-Knothole.

The Pharmacology and Toxicology Division, Atomic Energy Project (AEP), University of California at Los Angeles (UCLA), generously supplied caging and other animal facilities. Gerald Sprague and Phillip Noyes of this division are to be thanked for their participation in portions of the field testing.

The Colorimetric Dosimetry Section, AEP, UCLA, provided dosimeters and the personnel to interpret results.

Charles Rainey and James Neel evaluated the physical fall-out data collected by Project 27.1, thereby enabling a correlation of physical and biological measurements.

The entire Radio-Ecology Division, AEP, UCLA, wholeheartedly devoted its energies to the processing of overwhelming numbers of field samples.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The purpose of this investigation was to gather and interpret data pertaining to the biological fate of radioactive fall-out, originating from nuclear detonations, in areas adjacent to the Nevada Proving Grounds (NPG).

The need arose from the paucity of quantitative biological data pertaining to (1) the physical nature of fall-out materials and their influence on metabolic availability, (2) the degree of biological contamination in fall-out areas, (3) metabolic availability as a function of time and distance, (4) the potential hazard from radioactive fall-out areas, and (5) the correlation of these data as expressed in terms of the total environment.

The scope of this report includes contributions to each of these five items by presenting a history of repeated radioactive contaminations in selected areas adjacent to NPG during the period September 1951 through July 1953. An evaluation has been attempted of the biological fate of the various environmental contaminants through periodic radiological analyses of native soils, plants, and animals. General comparisons were made regarding the relative importance of short-term (acute) vs long-term (chronic) effects of radioactivity in these semi-arid environments.

1.2 BACKGROUND

The first investigation of this type was undertaken in New Mexico by the specially formed Alamogordo Section [now Radio-Ecology Division, Atomic Energy Project (AEP), University of California at Los Angeles (UCLA)]. Although the initial study began in 1947, two years after the first continental detonation, enough residual contamination was found to be of interest, and repeated studies of this area have continued to the present date.[1–5] Related studies in marine environments were undertaken in the Bikini and Eniwetok areas by the University of Washington Applied Fisheries Laboratory.[6–8]

More recently, detailed field studies were made of the effect of inhaled radioactivity on domestic animals exposed to the Jangle detonations of Operation Buster-Jangle by the Laboratory of Physical Biology, Public Health Service.[9] At the present time, biological monitoring programs are integral parts of such Atomic Energy Commission (AEC) facilities as Oak Ridge Operations, Savannah River Operations, and Hanford Operations. The Radio-Ecology Division, AEP, UCLA, is principally concerned with the over-all environmental effects of radioactive fall-out resulting from continental detonations.

1.3 OPERATIONS

The control or background data collected in 1951 were obtained by this group (AEP, UCLA) in anticipation of later work. In October 1952, following Operations Buster-Jangle and Tumbler-Snapper, a formal "reference" sampling was made by the Biological Field Survey Section of the Radio-Ecology Division, preparatory to participation in Operation Upshot-Knothole.

Biological sampling conducted during Operation Upshot-Knothole was done under the administrative direction of Project 27.2, Program 27 of the Civil Effects Test Group (CETG). It should be emphasized that the biological data have limited value without detailed physical measurements describing the total environmental contamination. Similarly the physical measurements lose perspective without correlation with biological fate and effect. Therefore Program 27 consisted of two integrated projects: (1) Project 27.1, primarily concerned with the physical dust and particulate sampling of fall-out, and (2) Project 27.2, primarily concerned with biological sampling. In June and July 1953, another survey was made of the Nevada area.

The total data in this report therefore represent a summary of several biological sampling periods as well as the integration of some physical measurements carried out by the Radio-Ecology Division, AEP, UCLA, during Operations Buster-Jangle, Tumbler-Snapper, and Upshot-Knothole.[3,10,11]

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CHAPTER 2

PROCEDURES

2.1 SAMPLING AREAS

Soil, plant, and animal control samples were taken from the region adjacent to NPG in September 1951. The main collection of control samples was obtained from the northeast quadrant in various locations at distances up to 40 miles from NPG. Although these samples were taken after Operation Ranger in January and February 1951, they were taken in areas outside the fall-out from that operation, and it is believed that the samples represent natural background activities for the general locality bordering NPG.* The Ranger detonations were all airdrops made over the Frenchman Flat area. Comparisons between sample radioactivities from these Nevada areas and from various uncontaminated locations in California[1] further justify the use of these data as natural environmental backgrounds.

Following the several fall-out contaminations by the detonations of Operations Buster-Jangle and Tumbler-Snapper, it became necessary to survey once more the region adjacent to NPG in order to establish existing levels of radioactivity preparatory to proposed work scheduled for Operation Upshot-Knothole.

Four "permanent" study areas were established in October 1952. They were chosen according to the degree of previous contamination (Table 2.1), their position relative to the test site (Fig. 2.1), and their environmental similarity.

The areas were defined by establishing two intersecting transects, 2000 ft in length, oriented north and south and east and west. Along these transects were plotted the position and type of each perennial plant, topographical features, soil contamination in milliroentgens per hour, soil type, and animal burrows. Samples of soils, plants, and animals were taken from each area for detailed radiological analysis. Water samples were taken from sources in the general operational area. Continuous impactor type air samplers[1] and hygrothermographs were maintained in areas I, II, and III, along with anemometers in areas I and III (see Fig. 2.1).

The study areas are characterized by arid to semi-arid type alluvial soils of recent geological origin overlain with varying degrees of "desert pavement" (Fig. 2.9). The predominant perennial plants are salt bush (*Atriplex*), horse bush (*Tetradymia*), Mormon tea (*Ephedera*), and rubber bush (*Chrysothamnus*). Small rodents are abundant in all areas with the white-footed mouse (*Peromyscus*, Fig. 2.2), kangaroo rat (*Dipodomys*, Fig. 2.3), and the jack rabbit (*Lepus*) demonstrating a nearly universal distribution. Also present in local areas are cottontail rabbits (*Sylvilagus*), pocket mice (*Perognathus*), wood rats (*Neotoma*), and antelope ground squirrels (*Citellus*). The presence of scattered Joshua trees (*Yucca brevifolia*) is a useful biological indicator of general climatic conditions. At present Joshua trees are found

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*Confirmed verbally by T. L. Shipman, Quarterly Meeting of Medical Directors, March 1953.

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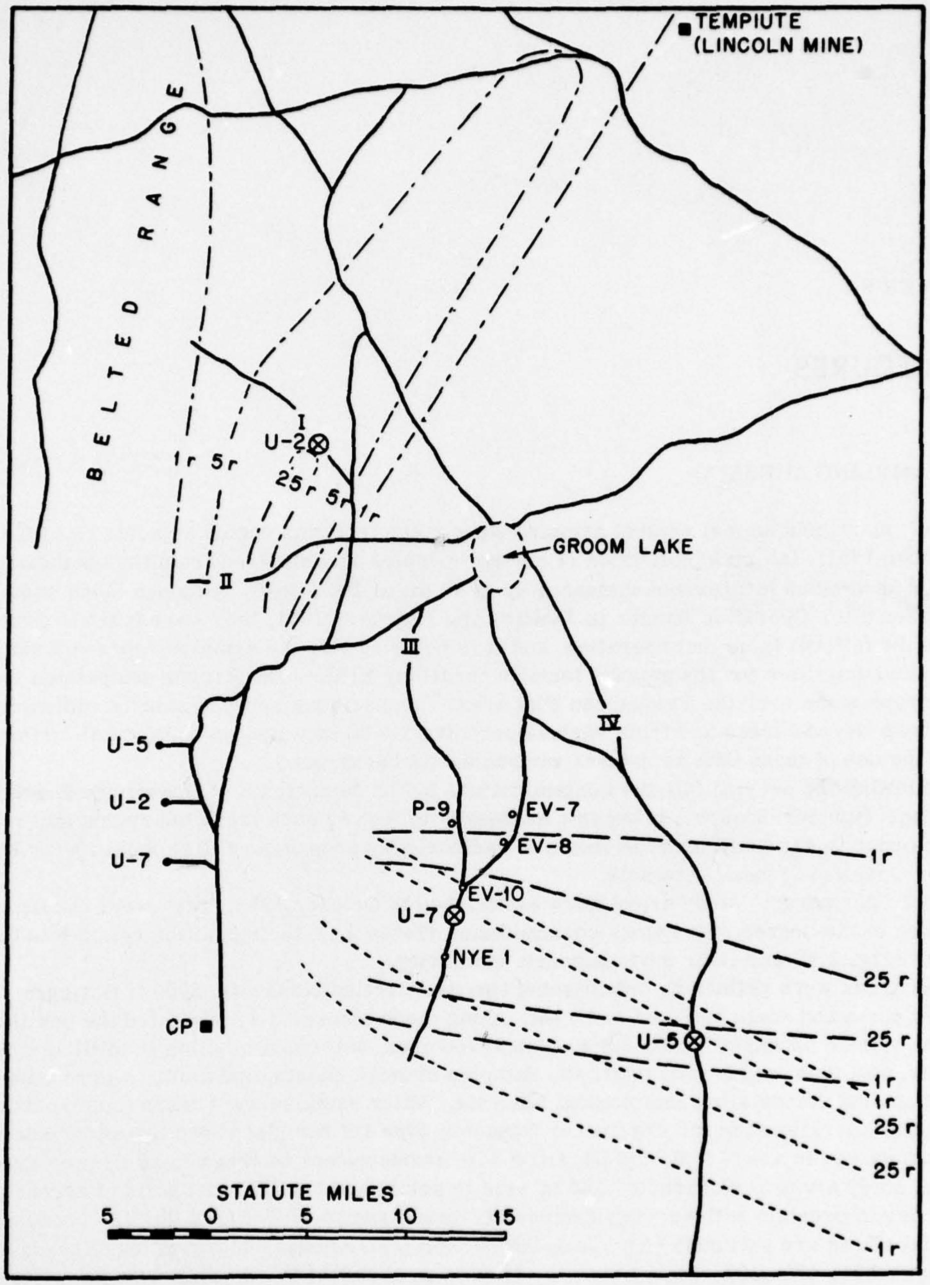

Fig. 2.1—Relative position of biological sampling areas to NPG and to the midline of fall-out resulting from Shots 2, 5, and 7. I, II, III, and IV are study areas. ⊗, sampling areas, Upshot-Knothole series. O, dosimetry stations, Shot 7. ●, Ground Zero. CP, Command Post. Isodose lines, infinite dosage, roentgens: ——·——, Shot 2; – – – – –, Shot 5; — — —, Shot 7.

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Fig. 2.2—White-footed mouse (*Peromyscus*). $^{1}/_{3}$ actual size

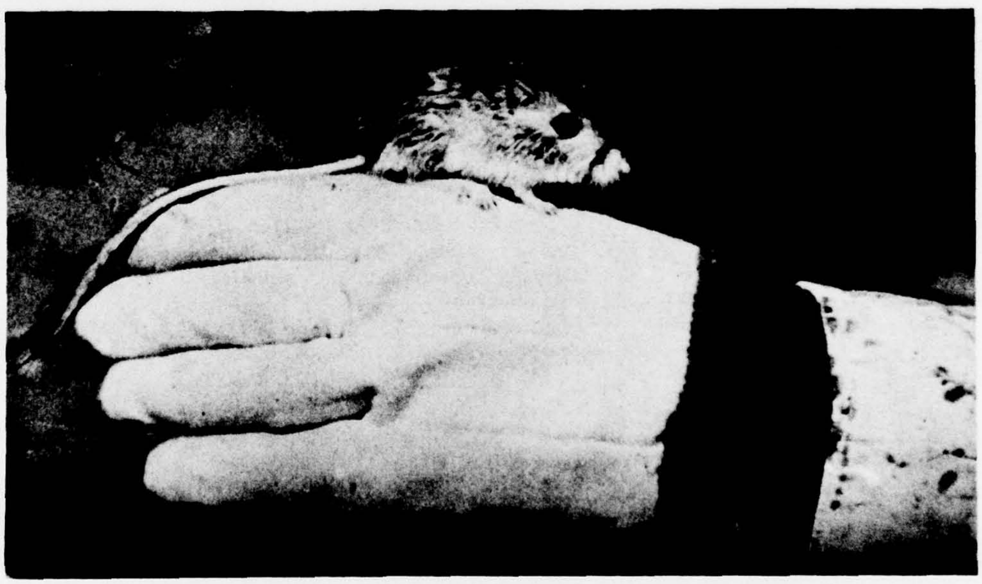

Fig. 2.3—Kangaroo rat (*Dipodomys*). $^{1}/_{3}$ actual size

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Table 2.1—HISTORICAL CONTAMINATION OF SELECTED BIOLOGICAL STUDY AREAS

Area	Distance and direction from CP*	Contamination at H + 12 hr, mr/hr: Jangle† Surface	Jangle† Underground	Snapper‡ 6	Snapper‡ 7	Snapper‡ 8	Residual contamination,§ October 1952, mr/hr
I	31 mi, NNE	238	80	75	100	Nil	2.2–3
II	24 mi, NNE	Nil	1538	104	510	Nil	5.0–8.2
III	23 mi, NE	Nil	Nil	180	Nil	Nil	0.54
IV	24 mi, ENE	Nil	Nil	1.2	Nil	Nil	Nil

*See Fig. 2.1.

†Operation Buster-Jangle, November 1951. Measurements were made by Radiac Tracerlab Model Su-10 survey meters held 3 ft above the soil surface.[2]

‡Operation Tumbler-Snapper, May and June 1952. Measurements were made with Beckman Model MX-5 G-M tube type survey instrument or, as needed, by a Tracerlab Model T1B ionization chamber. All measurements were taken 3 ft from the soil surface.[3]

§Biological Survey, October 1952. Negligible readings were obtained at 3 ft from the ground. Tabulated values were made with a Victoreen G-M type survey meter with the window open and held 1 in. from the soil surface.

only on and about the bases of those high desert ranges which receive a rainfall of 8 to 10 in. a year.[4] The region bordering NPG encompasses a wide variety of environments ranging from the relatively sterile and arid dry lakes to the heavy piñon-pine and juniper forests (Figs. 2.4 to 2.7). The similarity of radiological data collected from study area II and Nye Canyon to the data collected from the other more arid sampling areas suggests that the conditions described in this report apply to a wide variety of environmental situations.

The location and contamination of sampling areas studied during Operation Upshot-Knothole are summarized in Table 2.2. Of the "permanent" study areas established in October 1952, area I was recontaminated to a degree that warranted detailed study during the test series. It appears, however, that the entire 270° arc between northwest and southwest was contaminated to some degree by the Upshot-Knothole detonations. Therefore in June and July 1953 a

Table 2.2—LOCATION AND CONTAMINATION OF THE SAMPLING AREAS

Shot No.	Location of sampling area	Time of fall-out	Estimated activity at fall-out time, r/hr	Time of initial sampling	Radiation at beginning of sampling,* mr/hr
2	19 mi NE of Ground Zero†	H + 1 hr (est.)	5	H + 12 hr	250
				D + 9 days	6
				D + 22 days	2.5
				D + 38 days	2
				D + 96 days	1–2
5	31 mi SE of Ground Zero	H + 1 hr (est.)	12	H + 10 hr	740
7	16 mi SE of Ground Zero (Nye Canyon, 1.5 mi N, Nye 1)	H + 40 min (recorded)	20	H + 12 hr	700

*Readings were taken approximately 3 ft from soil surface on D-day, and at 1 in. above the soil surface thereafter, with the Jordan Model AG 500 Gamma Radiation Monitor and the Precision Model 106 Portable G-M Survey Meter.

†This area was established in October 1952. A study of over-all "environmental decay" due to a single detonation from Operation Upshot-Knothole is therefore possible.

[redacted]

Fig. 2.4—Salt bush (*Sarcobatus*) growing at margin of Groom Dry Lake, 25 miles northeast of CP, NPG.

Fig. 2.5—Salt-bush association, study area III, 20 miles northeast of CP. Note the salt bush (*Atriplex*), rubber bush (*Chrysothamnus*), and scattered Joshua trees (*Yucca brevifolia*) on the slope.

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Fig. 2.6—Sage-brush association, study area II, 25 miles north of CP. Sage brush (*Artemesia*) is shown growing on the rocky canyon slope.

Fig. 2.7—Piñon-pine-juniper association, Bald Mountain Road, 30 miles northeast of CP. There is a dense piñon-pine forest on the slope of the peak.

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general resurvey was made of all four "permanent" study areas, plus the Shot 7 sampling area in Nye Canyon.

2.2 SAMPLING METHODS

2.2.1 Soils

Two techniques were used to trace the fate of residual contamination on soils. The first method determined the total radioactive material per unit of surface area by sampling 1 ft^2 of soil, approximately 1 in. deep (Fig. 2.8). The second method measured the migration of radioactive material through the soil by sampling soil profiles in increments of 1 in. or more and expressing the activity at each depth in terms of unit weight (Fig. 2.9).

In the laboratory the surface sample was sieved and weighed, and the coarse material (greater than 2 mm diameter) was discarded since it contained negligible radioactive material when compared to the finer fraction. A 200-g sample of the sieved material was placed in a shallow cardboard tray and counted, using a gas-flow beta proportional counter. The observed counts were corrected for self-absorption and for sample and counter geometry.

To determine the distribution of radioactive material as a function of particle size, the bulk material was further separated by mechanical sieving into eight size fractions. Three 1-g aliquots of each size fraction were counted using an end-window G-M tube (1.5 mg/cm^2). In this case, observed counts were corrected for sample and counter geometry. The details of these procedures are presented in the report[5] of Project 27.1.

In the laboratory the profile samples were also weighed and sieved, and the coarse material was discarded. One-gram aliquots of the sieved soil were counted, using an end-window G-M tube (1.5 mg/cm^2). Observed counts were corrected for sample and counter geometry.

2.2.2 Plants

Plant material was sampled in the field by taking three to five replicates of top growth from each of several plant species in an area. Each replicate was sealed in a heavy paper bag for transport to the laboratory.

In the laboratory each replicate was divided. One portion was washed in a concentrated detergent solution and rinsed in tap and distilled water; the other was not. It should be noted that, even after thorough washing and mechanical scrubbing, small soil and/or fall-out particles can be detected adhering to the plant. The comparative count of the washed and unwashed samples is therefore considered to be only an indication of the relative amount of external contamination and not a measure of metabolic uptake.[6]

After washing, both fractions were oven-dried for 12 to 16 hr and then ground in a Wiley Mill through a 20-mesh screen. This dried ground material was counted in $\frac{1}{2}$-g aliquots. It was determined that this amount of material represented infinite sample thickness, thereby approximating self-absorption corrections. Observed counts were corrected for sample and instrument geometry, using U_3O_8 as a reference.

2.2.3 Animals

The choice of study animals was determined by their abundance, year-around availability, ease of sampling, and their being of mammalian types. The smaller species (i.e., white-footed mice, kangaroo rats, and wood rats) were collected, using patented metal, treadle type live traps, baited with rolled oats, and placed 50 to 100 ft apart along transects running through areas of interest (Fig. 2.10). Larger live traps of the "Hav-a-hart" design were used for cottontail rabbits (*Sylvilagus*). Jack rabbits were collected at night or in the early morning, using .22 caliber rifles and spotlights. In all, approximately 700 animals have been sampled by these means with an average trap-line yield of 25 to 35 per cent. Approximately 200 small rodents have been marked by toe clipping and ear notching and released in anticipation of subsequent detailed population studies.

Another method of study involved the use of captive animals. Live native rodents, collected from uncontaminated areas prior to scheduled detonations, were held in hardware-cloth cages

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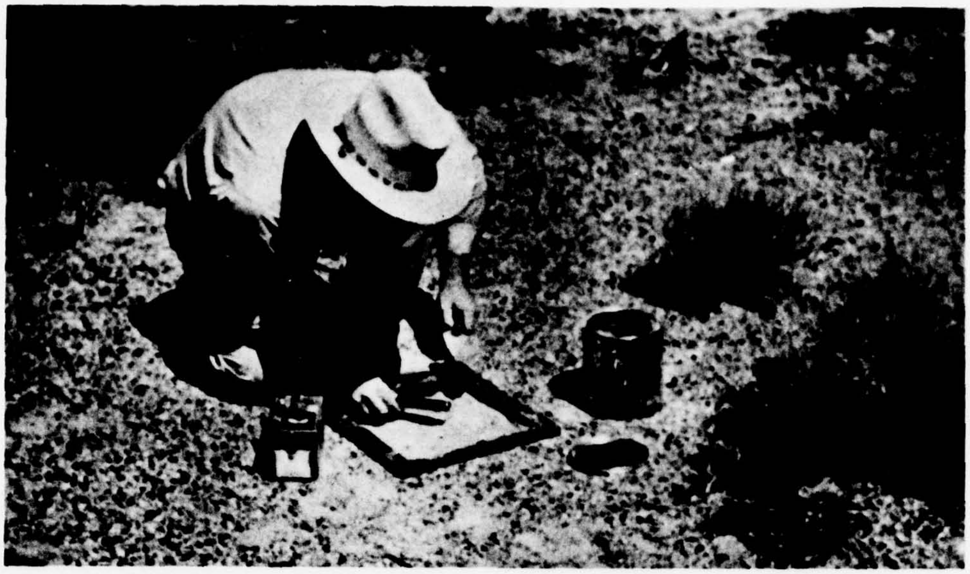

Fig. 2.8—Sampling surface soil, using the template method. Sampling areas were 1 ft^2 and approximately 1 in. deep. A survey meter was used to check the degree of removal of radioactive material.

Fig. 2.9—Studying and sampling a soil profile. Note the wind-eroded soil surface resulting in a typical residual deposit of surface gravel characteristic in the early formation of "desert pavement."

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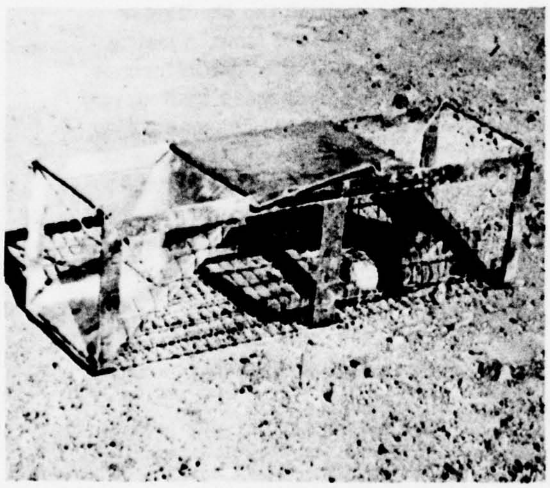
(a)

(b)



(c)

(d)

Fig. 2.10—Trapping methods. (a) Laying trap line; traps are carried in metal bins on both sides of the truck. (b) Placing a metal treadle trap. (c) Large live trap used for collecting cottontail rabbits. (d) Kangaroo rats placed for exposure to fall-out at an air-sampling station.

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located at dust- and particulate-sampling stations maintained by Project 27.1 (Fig. 2.10). Thus, depending on the degree of contamination by fall-out, it was possible to obtain correlated data pertaining to physical contamination, dosimetry, and animal uptake of radioactive materials.

Trapping and collecting usually began 12 hr after the detonation and continued until all traps and cages were retrieved 12 hr later. Data regarding trap yield, species involved, sex, and routine monitoring information were then recorded. The animals were immediately sacrificed by placing them in a dry-ice chamber. Frozen specimens, individually sealed in plastic bags, were shipped via air freight to the laboratory at UCLA for detailed autopsy and analysis.

In the laboratory, specimens were thawed, dipped in hot paraffin, and autopsied. The paraffin dip satisfactorily sealed the fur and minimized the possibility of contaminating internal organs with radioactive fall-out material and dust from the pelt. The levels and types of radiation found in different organs often necessitated the use of more than one organ of a given type to provide a sufficient amount of tissue ash for a satisfactory count. As a result, where numerous specimens were available, two to four livers or two to four femurs, etc., were combined for radiological analysis. In all cases, enough "groups" of animals were used to ensure the obtaining of a representative sample. Routine tissue samples consisted of lung, gastrointestinal tract or caecum, liver, femur, and the muscles associated with the femur (in most cases, the sartorius). This choice of tissue samples was made on the assumption that radioactive materials detected in the lung and the gastrointestinal tract would provide data on the path of uptake, while radioactive materials absorbed from these sources would most probably be detected in the liver on the way to distribution throughout the body and would also be detected in the bone because of the known presence of "bone-seeking" isotopes in gross fission products.

Comparative assays of field samples, using wet ash and dry (ignition) ash preparations failed to reveal significant differences in sensitivity. Dry ashing was chosen as the routine treatment since, under existing laboratory facilities, dry ashing permitted the handling of larger masses of tissue and more individual samples in a shorter period of time. Tissues were placed in pyrex beakers, dried for 12 to 16 hr at 120°C, and placed in a muffle furnace. There the samples were preheated at 350°C until fuming began. The fumes were ignited, and the final furnace temperature set at 540°C for 12 to 16 hr. After cooling, the ash was pulverized in the beakers, and 100-mg aliquots were counted on a Tracerlab Autoscaler, using an end-window G-M tube (1.5 mg/cm^2). The observed counts were corrected for sample and instrument geometry, using U_3O_8 as a reference. Since no self-absorption corrections were made, it is probable that the tissue activities reported are low because of the presence of low-energy isotopes (see Chap. 4).

2.2.4 Airborne Radioactive Material

The methods and instrumentation used in determining airborne contamination are described in detail in the report[5] of Project 27.1. In general, both Lo-Vol (≈0.5 cfm) and Hi-Vol (≈20 cfm) types of air samplers were used with both Mine Safety Appliance All Dust and Millipore membrane type filtering media. Particle-size determinations were made with the aid of Casella cascade impactors.

It is difficult under ideal conditions to obtain representative samples of aerosols from any single location. Because of this and the inefficiency of existing air-sampling equipment,[5] it may be misleading to use an isolated bit of data as a representative value. In the discussion of inhalation of radioactivity, however, it becomes necessary to discuss airborne concentration of radioactive material at the Nye 1 station in just this way. Although those data may be in error by an order of magnitude, for purposes of discussion they have been accepted as reasonably valid.

2.2.5 Dosimetry

The determination of radiation exposure was largely derived from film badges, area monitoring, and calculations derived from soil contamination and gummed-paper analyses. The details of these techniques and the compilation of data are presented in the report[5] of Project 27.1.

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In addition, domestic "Dutch Breed" rabbits, bearing internal chemical dosimeters, were exposed in hardware-cloth cages ($^1/_2$-in. mesh) at various sampling stations maintained by Project 27.1. The dosimeters were developed and furnished by the Colorimetric Dosimetry Section, Diversified Problems Division, AEP, UCLA. These dosimeters were relatively energy-independent with a minimum energy sensitivity of approximately 125 kv for a gamma radiation and a minimum dose sensitivity of 10 per cent of the dosimeter range which became more accurate with increasing doses (calibrated against 125-kvp X ray). Two r-dosimeters, encased in glass, were surgically placed in the abdominal cavity of each rabbit, and the incision was allowed to heal before the animals were transported to the field and exposed. Matching dosimeters were placed on the cages, as well as two 50-r dosimeters, one of which was wrapped in lead foil. All external dosimeters were wrapped in aluminum foil to shield them from light. All cages were placed at air-sampling stations, 2 to 4 hr prior to the detonations.

Calculations of internal dose in reps were made according to the equation[7]

$$\text{Reps/min} = \frac{(\text{dis/min/g})(0.75)(1.6 \times 10^{-6})}{83} \tag{2.1}$$

where dis/min/g = concentration of activity

0.75 = average beta energy of contaminants as measured

1.6×10^{-6} = conversion factor, million electron volts to ergs

83 = ergs per gram per rep

With the exception of thyroid contamination, radioactivity in tissues had the characteristics of mixed fission products. Corrections and extrapolations for decay were therefore made according to the equation[8]

$$A = A_0 t^{-1.2} \tag{2.2}$$

where A_0 = activity at unit time

A = activity at time t

t = time

−1.2 = decay constant for gross fission product

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[redacted]

CHAPTER 3

RESULTS

3.1 SOILS

Data pertaining to the surface contamination of soil and the migration of surface activity through the soil were collected in September 1951, October 1952, and March, April, and July 1953. The results are summarized in Table 3.1, which suggests that:

1. The average content of radioactive material on soil from areas adjacent to NPG prior to contamination by nuclear detonations was 94 dis/min/g (surface soil sampled to a depth of 6 in.).
2. Variations of natural backgrounds in different Nevada locations can be explained in terms of the occurrence of the highly mobile potassium salts and further by the occurrence of trace amounts of radioactive isotopes of various heavy metals associated with ore deposits of silver, lead, and tungsten. As a result, the average soil background in Nevada was slightly higher than the maximum value of 75.6 dis/min/g obtained from control soils in Southern California.[1]
3. Background radioactivity was not increased for soil 2 in. or more below the surface.
4. Therefore it may be concluded that, for the type of detonations studied in the desert environment, contamination by fall-out is a surface phenomenon, even after a period of two years.
5. A very low degree of solubility of contaminants may be postulated.

3.2 PLANTS

The summarized data pertaining to radioactivity associated with plant material are presented in Table 3.2. A considerable degree of variation will be noted. The "normal" radiation levels established in September 1951 are prime examples. These variations may be accounted for according to the nutritional requirements of different species of plants and the natural variations in the normal content of radioactive materials in the soil. The purposes in obtaining the data were (1) to determine the characteristics and rate of metabolic accumulation of radioactive material by plants in the natural desert environment and (2) to estimate the quantity of radioactive material that would be ingested by animals feeding on contaminated forage plants.

The fact that these studies were initiated in detail during the periods of variable seasonal drought has thus far largely limited the sampling of plant material to perennial species. The inherent scrubbiness of desert plants and their small bract-like leaves, sticky surfaces, hairs, and spines have made it difficult to differentiate between metabolic uptake of radioactive materials and external contamination.[3] Pending the development of more definitive techniques, emphasis in field sampling has been placed on determining the total activity associated with plant material in the environment rather than that associated with plant uptake.

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Table 3.1 — RADIOACTIVE MATERIAL ASSOCIATED WITH SOIL FROM BIOLOGICAL SAMPLING AREAS REPEATEDLY CONTAMINATED BY RADIOACTIVE FALL-OUT

Area	Contamination from detonations	Sampling* date	Counting date	Activity, $\mu c/ft^2$	Disintegration rate, dis/min/g, at indicated depth 0–1 in.	1–2 in.	2–3 in.
I	None	9/3/51	10/14/53	5.36×10^{-2}	6.89×10		
	Jangle Series						
	Snapper 6 and 7	10/28/52			1.08×10^{3}	131	81
	Upshot 2	3/30/53	4/24/53	1.34×10^{3}†	1.83×10^{7}		
		7/1/53	10/14/53	2.48×10^{0}	3.21×10^{3}		
II	None	9/12/51	10/14/53	5.16×10^{-2}	1.05×10^{2}		
	Jangle Underground						
	Snapper 6 and 7	10/28/52			2.91×10^{3}	138	93
	Upshot 2	3/30/53	4/24/53	1.34×10^{3}†	2.3×10^{7}		
		7/1/53	10/14/53	3.36×10^{0}	6.81×10^{3}	1960	121
III	None	9/12/51	10/14/53	5.4×10^{-2}	1.17×10^{2}		
	Snapper 6	10/28/52			8.70×10^{2}	117	75
	Upshot (?)	7/2/53	10/14/53	5.59×10^{-1}	1.21×10^{3}		
IV	None	9/13/51	10/14/53	2.27×10^{-2}	8.8×10		
		10/28/52			9.6×10	80	92
	Upshot (?)	6/28/53	10/14/53	3.71×10^{-1}	1.44×10^{3}		
Nye 1	None	9/13/51‡	10/14/53	4.53×10^{-2}	$9\ 2 \times 10$		
	Upshot 5	4/18/53		2.19×10^{4}	2.4×10^{6}		
	Upshot 7	4/25/53		1.85×10^{4}	2.0×10^{7}		
		7/3/53	10/14/53	1.93×10	6.4×10^{4}		

*Because of repeated contaminations, no attempt was made to extrapolate observed disintegration rates of residual contamination to a common time.

†Approximate values derived from monitoring data at H + 12 hr (see Ref. 2).

‡Sample taken at soil stake 25, approximately 3 miles north of Nye 1.

Table 3.2 — RADIOACTIVE CONTAMINATION ASSOCIATED WITH PLANT MATERIAL REPEATEDLY CONTAMINATED BY RADIOACTIVE FALL-OUT

Area	Sampling* date	Counting date	No. of species	Disintegration rate, dis/min/g of plant dry material: Unwashed Minimum	Unwashed Maximum	Unwashed Average	Washed Minimum	Washed Maximum	Washed Average
Groom Lake and vicinity	9/3/51	10/26/53	6	1.2×10	7.59×10	3.98×10			
I	11/1/52	12/5/53	3	9.9×10	1.39×10^{2}	1.14×10^{2}			9.06×10
	3/25/53	3/30/53	2	3.23×10^{5}†	4.95×10^{5}†	4.09×10^{5}†	1.29×10^{5}	1.44×10^{5}†	1.36×10^{5}†
	7/1/53	7/30/53	4	1.22×10^{2}	3.68×10^{2}	2.46×10^{2}	4.6×10	1.45×10^{2}	9.1×10
II	11/1/52	12/5/53	4	5.46×10	2.66×10^{2}	1.6×10^{2}	8.76×10	9.48×10	7.85×10
	7/1/53	9/23/53	4	1.27×10^{2}	1.69×10^{2}	1.49×10^{2}	3.89×10	1.05×10^{2}	8.0×10
III	11/1/52	12/5/53	4	1.72×10^{2}	4.89×10^{2}	3.21×10^{2}	3.66×10	7.08×10	5.37×10
	7/1/53	9/22/53	4	1.16×10^{2}	1.65×10^{2}	1.42×10^{2}	1.05×10^{2}	1.54×10^{2}	1.36×10^{2}
IV	11/1/52	12/5/53	5	2.34×10	6.87×10	4.2×10	1.68×10	3.66×10	2.68×10
	7/1/53	9/23/53	3	4.9×10	2.64×10^{2}	1.63×10^{2}	3.63×10	9.55×10	6.69×10
Nye 1	4/25/53	5/12/53	1			9.97×10^{5}†			2.19×10^{5}†
	7/1/53	7/30/53	4	4.39×10^{3}	1.03×10^{4}	7.25×10^{3}	1.91×10^{3}	3.43×10^{3}	2.66×10^{3}

* Because of repeated contaminations, no attempt was made to extrapolate observed disintegration rates of residual contamination to a common time.

† Values extrapolated to 12 hr after observed detonation.

[redacted]

The data do suggest, however, that the average residual radioactive material associated with washed plant material four to six weeks after contamination is twice the maximum background values established in September 1951. The washed samples from area III (1953) significantly increase the over-all average value. The measured values from area III (1953) are approximately three times greater than values of equivalent samples obtained in November 1952. This suggests either that the residual radiation from the Operation Snapper contaminations is becoming metabolically more available or that the area was recontaminated during Operation Upshot-Knothole. A similar situation exists in area IV. Although the first possibility cannot be ruled out, the general contamination of the two eastern quadrants by Operation Upshot-Knothole makes recontamination a more likely explanation.[2]

Assuming that the samples were properly handled in the laboratory, the close agreement between washed and unwashed samples from area III (1953) is difficult to explain. The high degree of contamination associated with washed plant material, particularly the values at H + 12 hr, cannot at this time be entirely discounted as external contamination. The possibility still exists that, in the early hours following a detonation, significant contamination in a colloidal state may have entered the plants through the aerial portions and entered into the metabolic processes. Interestingly, all the species sampled (excepting area I, collected Mar. 25, 1953, and Nye 1, collected May 12, 1953) are perennials. The soil data and the characteristic root system of perennial plants tend to confirm the assumption that the uptake, if real, may be principally through the aerial parts of the plant. A definite statement cannot be made at this time as to the exact pathway.

The theoretical maximum amount of radioactive material that could be ingested by animals feeding on contaminated forage is indicated by the radioactive contamination of unwashed plant material. Thus, on D-day of Shot 7, a kangaroo rat, feeding in the vicinity of Nye 1 at a rate of 10 g of air-dried plant substance per day, would in one day consume 4.5 μc of radioactive material. A cow, foraging in the same area at a rate of 30 lb (13,608 g) of dried material per day would in one day consume 6124 μc of radioactive material.

The data as presented may be summarized as follows:

1. As a result of a series of contaminations by nuclear detonations over the past two years, there is possibly a slight increase in measured metabolic radioactive contaminants in plant material over the September 1951 values.
2. The greatest proportion of contamination associated with plant material may be attributed to external sources.
3. A possibility exists that the nature of early fission product material may permit significant amounts of radioactive material to enter through the aerial parts of plants.
4. The total amount of contamination consumed by a domestic animal (16 miles from Ground Zero, Nye 1 area), feeding on contaminated forage plants during D-day, may have reached several thousand microcuries, depending on the feeding rate of the animal.

3.3 ANIMALS

Biological study area I (19 miles northeast of Shot 2 Ground Zero), established in October 1952, is of particular interest because of its lack of contamination by succeeding shots of Operation Upshot-Knothole, thus permitting subsequent animal samples to be taken on the day of Shot 2, and serially 9, 23, 38, and 96 days later. This serial sampling provided data on the persistence and biological fate of radioactive fall-out resulting from a single detonation.

The persistence of radioactive contamination in the field has been termed "environmental decay" by this organization since persistence involves both the characteristic radioactive decay and the modifications of concentration of radioactive fall-out materials brought about by the uncertainties of the natural environment.

The data gathered by radiological analysis of small rodents trapped in area I, after contamination by Shot 2, are presented in Table 3.3. Similar data are presented in Table 3.4 for jack rabbits. Since it was estimated that an excessive radiation dose would have been received by the personnel during collecting, jack rabbits were not sampled on the day of the detonation.

Table 3.3—RADIOACTIVE MATERIAL IN KANGAROO-RAT TISSUE RESULTING FROM FALL-OUT CONTAMINATION* BY SHOT 2 AS COMPARED TO REFERENCE ACTIVITIES OBTAINED IN OCTOBER 1952

Time sample taken, days after shot	No. of animals sampled	Average activity at time of sampling									
		Lung		GI tract and contents		Liver		Muscle (sartorius)		Femur	
		Dis/min/100 mg of ash	$\mu c \times 10^{-5}$ per organ†	Dis/min/100 mg of ash	$\mu c \times 10^{-5}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-5}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-5}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-5}$ per organ
1	32	15,164	93	232,988	21,000	32,619	550	13,076	100	462	15
9	7	991	3.5	7,290	470	4,553	77	530	14	123	3.8
23	9	201	1.1	2,311	140	226	3.8	189	2.8	38	0.86
38	13	99	0.77	1,647	210	119	3.8	44	0.77	24	0.77
96	12	44	0.14	120	7.7	43	0.36	42	0.27	7.2	0.22
Oct. 1952	8	35	0.09	91	5.5	39	0.32	33	0.36	12	0.48

*Nineteen miles from Ground Zero.

†Average organ weight of fresh tissue: lung, 0.57 g; GI tract and contents, 6.26 g; liver, 2.29 g; sartorius, 1.31 g; femur, 1.41 g.

Table 3.4—RADIOACTIVE MATERIAL IN JACK-RABBIT TISSUE RESULTING FROM FALL-OUT CONTAMINATION* BY SHOT 2 AS COMPARED TO REFERENCE ACTIVITIES OBTAINED IN SEPTEMBER 1951 AND OCTOBER 1952

Time sample taken, days after shot	No. of animals sampled	Average activity at time of sampling									
		Lung		Caecum and contents		Liver		Muscle (sartorius)		Femur	
		Dis/min/100 mg of ash	$\mu c \times 10^{-4}$ per organ†	Dis/min/100 mg of ash	$\mu c \times 10^{-4}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-4}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-4}$ per organ	Dis/min/100 mg of ash	$\mu c \times 10^{-4}$ per organ
9	7	1744	22	12,455	880	2793	15	211	9.7	71	10
23	4	119	6.5	3,012	420	59	9.2	39	1.7	44	6.1
38	2	107	7.9	2,064	370	82	15	40	2.4	33	5.3
96	5	49	0.61	471	75	29	1.0	23	0.26	7	0.96
Oct. 1952	5	11	0.67	270	49	13	1.2	32	1.4	20	2.4
Sept. 1951	10			10	3.2	11	0.34	25	0.38	2	0.19

*Nineteen miles from Ground Zero.

†Average organ weight of fresh tissue: lung, 27.2 g; caecum and contents, 124 g; liver, 46.2 g; sartorius, 22 g; femur, 15 g.

[redacted]

Natural background activities as determined in September 1951 and residual activity as determined in October 1952 are presented for reference. Activities are expressed in terms of unit weight of ash and per organ. Thus it is possible to determine the relative concentration of activity per unit weight of tissue and also the relative distribution of activity through the organ systems. Figures 3.1 and 3.2 are graphical summaries of the residual activity in the population as a function of time. For further reference, the gross fission decay rate of gummed papers and the gross fission decay rate of air filters as determined by Project 27.1 are plotted.[2]

Data obtained from animals sampled 31 miles southeast of Ground Zero after Shot 5 are summarized in Table 3.5. The data are reported according to species. Although variations will be noted, comparisons of radioactivity per unit weight of tissue ash reveal no consistent differences in uptake between species.

Table 3.5 — RADIOACTIVE MATERIAL IN ANIMAL TISSUE RESULTING FROM FALL-OUT CONTAMINATION* BY SHOT 5

Species	No. of animals collected	Average activity at time of sacrifice (H + 24 hr)					
		Dis/min ($\times 10^4$) per 100 mg of ash	$\mu c \times 10^{-2}$ per organ	Dis/min ($\times 10^4$) per 100 mg of ash	$\mu c \times 10^{-2}$ per organ	Dis/min ($\times 10^4$) per 100 mg of ash	$\mu c \times 10^{-2}$ per organ
		Lung		GI tract and contents		Liver	
Pocket mouse (*Perognathus*)	29	4.78	0.52	1839	467	62.9	6.59
White-footed mouse (*Peromyscus*)	8	48.3	5.50	2154	1420	140	14.6
Kangaroo rat (*Dipodomys*)	1	2.32	1.05	3031	1790	66.2	32.8
		Muscle (sartorius)				Femur	
Pocket mouse (*Perognathus*)	29	51.9	1.39			1.23	0.15
White-footed mouse (*Peromyscus*)	8	100	2.83			6.76	0.53
Kangaroo rat (*Dipodomys*)	1	37.7	2.92			1.45	0.37

*Thirty-one miles from Ground Zero; sampling period, H + 12 hr to H + 24 hr.

Data obtained from animals sampled 15 miles east southeast of Ground Zero after Shot 7 are presented in Table 3.6. Caged domestic rabbits bearing internal and external chemical dosimeters and caged native rodents were held at the Nye 1 dust and particulate station near the midline of fall-out. Because of the exposed position of the caged animals and the extreme weather conditions, it was necessary to provide the caged animals with food and water to ensure their survival. Uptake of radioactivity by the exposed animals must therefore be attributed to both inhalation and ingestion.

After the cages had been positioned and prior to the detonation, two of the captive native rodents were immediately sacrificed. These controls were necessary because the general area in which the cages were placed had been previously contaminated by one or more earlier shots of Operation Upshot-Knothole. It is believed that the control values represent contamination received by the caged animals as they were transported through contaminated areas to the experimental site. The gamma-dosage measurements obtained by chemical dosimeters used in conjunction with the caged animals are summarized in Table 3.7.

A trap sample was obtained 1.5 miles north of the Nye 1 station in an area of lesser contamination. Although data are presented for both caged and trapped animals exposed to fall-out from Shot 7, the data are not strictly comparable.

Estimates of total body uptake are made by assuming that, as in the laboratory white rat, the femur represents $\frac{1}{20}$ of the skeletal weight. The derived skeletal weight subtracted from the carcass weight gives the weight of the musculature. Thus, by totaling the activity in the skeleton, musculature, liver, and thyroid, a reasonable estimate of metabolized activity may be made. It appears that other tissues make negligible contributions to this total (see Table 3.8).

[redacted]

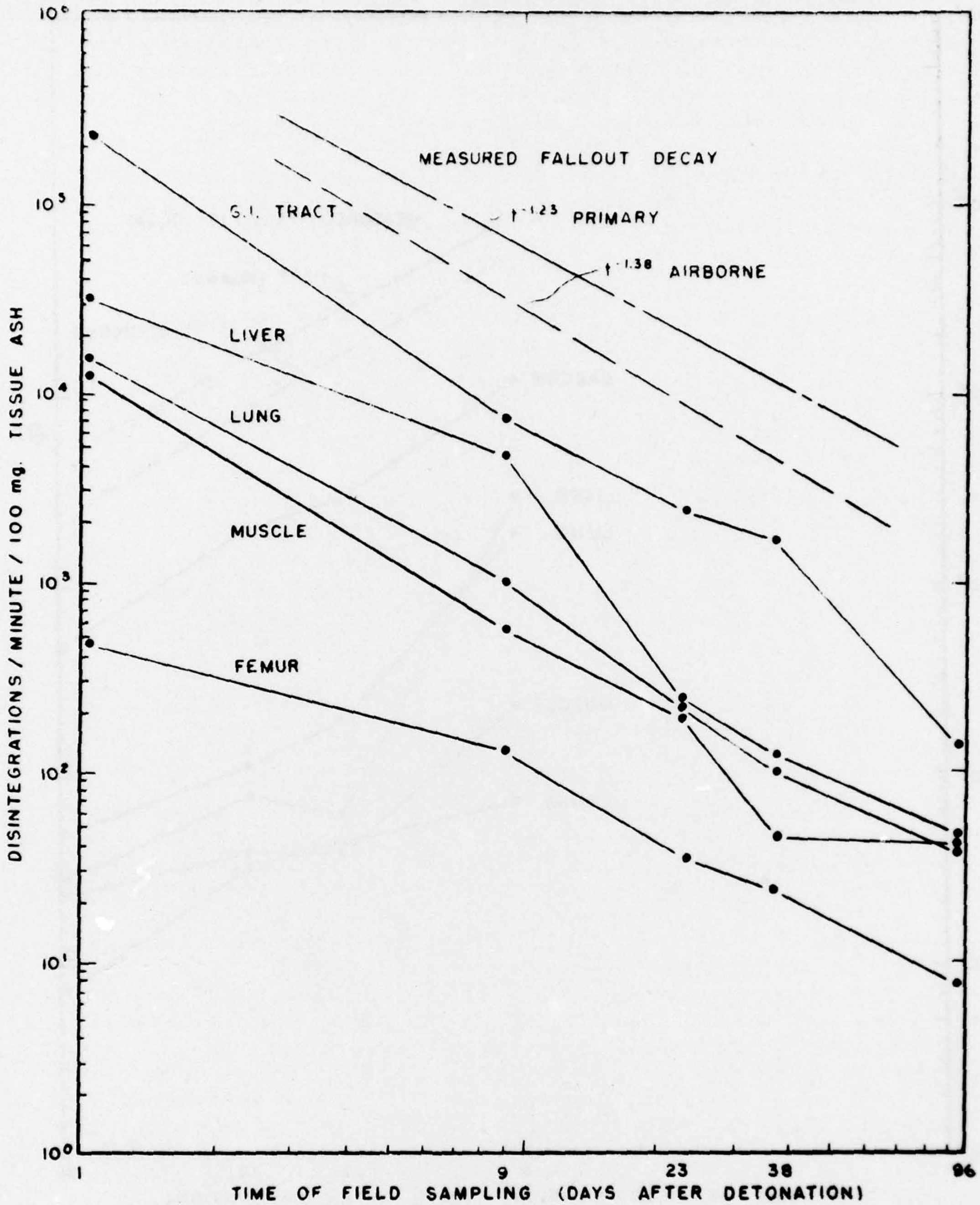

Fig. 3.1—Residual absorbed radioactive material remaining in a natural population of kangaroo rats contaminated by Shot 2, 19 miles from Ground Zero.

[redacted]

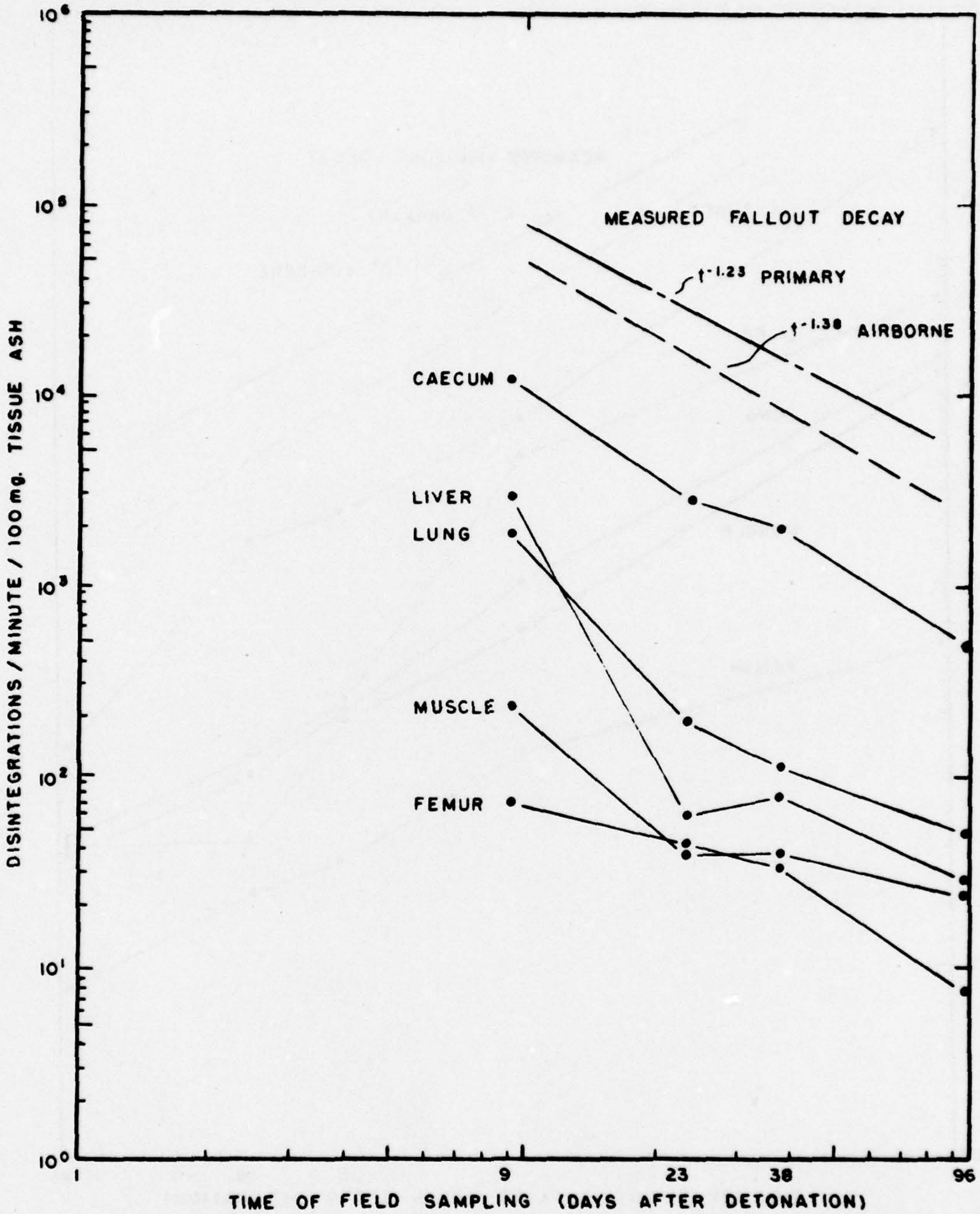

Fig. 3.2—Residual absorbed radioactive material remaining in a natural population of jack rabbits contaminated by Shot 2, 19 miles from Ground Zero.

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Table 3.6—RADIOACTIVE MATERIAL IN ANIMAL TISSUE RESULTING FROM FALL-OUT CONTAMINATION* BY SHOT 7

Species	Caged domestic rabbits	Caged native rodents	Control native rodents†	Trapped native rodents‡
Number of animals used for average	4	4	2	19
Average activity at time of sacrifice (H + 24 hr)				
Lung				
Dis/min ($\times 10^3$) per 100 mg of ash	9.21	2.41	0.70	10.5
$\mu c \times 10^{-3}$ per organ	12.0	3.14	0.04	0.59
Caecum and contents§				
Dis/min ($\times 10^3$) per 100 mg of ash	274	484	0.13	238
$\mu c \times 10^{-3}$ per organ	4230	609	0.07	183
Liver				
Dis/min ($\times 10^3$) per 100 mg of ash	7.03	15.1	0.56	4.28
$\mu c \times 10^{-3}$ per organ	99.6	10.2	0.05	6.78
Muscle (sartorius)				
Dis/min ($\times 10^3$) per 100 mg of ash	8.52	60.6	0.49	4.77
$\mu c \times 10^{-3}$ per organ	13.9	9.9	0.03	0.29
Est. $\mu c \times 10^{-3}$, total muscle	1650	210		16.2
Femur				
Dis/min ($\times 10^3$) per 100 mg of ash	0.82	2.36	0.03	0.29
$\mu c \times 10^{-3}$ per organ	8.96	1.4	0.002	0.79
Est. $\mu c \times 10^{-3}$, total skeleton	140	17		5.79
Thyroid, $\mu c \times 10^{-3}$ per organ	34	73		1.36
Est. total activity absorbed and/or metabolized, μc	1.92	0.245		0.030

*Sixteen miles from Ground Zero. Caged samples were exposed from H + 1 hr to H + 24 hr; trapped samples were obtained from H + 1 hr to H + 24 hr, 2 miles north of the caged samples.

†Control native rodents were collected south of Mercury.

‡Sample obtained 1.5 miles north of caged animals in area of lesser contamination.

§Gastrointestinal tract plus contents for native rodents.

Table 3.7—GAMMA-RADIATION DOSE RESULTING FROM FALL-OUT* OF SHOT 7 AS DETERMINED BY INTERNAL AND EXTERNAL CHEMICAL DOSIMETERS FROM CAGED DOMESTIC RABBITS†

Station‡	Cage No.	External dose, r/24 hr	Rabbit No.	Internal dose, r/24 hr
P-9	1	(1.7−2.0) ± 0.2	1	§
			2	0.3 ± 0.2
	2	1.2 ± 0.2	3	§
			4	§
EV-7	1	(0.69−0.90) ± 0.2	1	§
			2	0.35 ± 0.2
EV-8	1	(0.6−0.75) ± 0.2	1	§
			2	§
	2	1.2 ± 0.2	3	§
			4	§
EV-10	1	12.0 ± 5	1	2.2 ± 0.2
			2	2.2 ± 0.2
	2	4.3 ± 5	3	1.5 ± 0.2
			4	1.5 ± 0.2
Nye 1	1	50.0 ± 5	1	13.0 ± 0.2
			2	15.0 ± 0.2
	2	65.0 ± 5	3	20.0 ± 0.2
			4	20.0 ± 0.2

*Sixteen miles from Ground Zero.

†Operation Upshot-Knothole Project 29.1 Report, WT-802.

‡See Fig. 2.1 for locations.

§Not significant, reading not accurate; less than 0.2 r.

[redacted]

In Table 3.8 are given the data obtained from assorted tissues sampled during Operation Upshot-Knothole. As would be expected, this table demonstrates that the distribution of absorbed radioactive materials is general. Perhaps most noteworthy is the concentration of

Table 3.8—RADIOACTIVE MATERIAL IN ASSORTED ANIMAL TISSUE CONTAMINATED BY FALL-OUT DURING OPERATION UPSHOT-KNOTHOLE*

Tissue or organ	Species	Shot No.	Date collected, 1953	No. of animals	Average activity per organ	
					Dis/min	$\mu c \times 10^{-5}$
Fetus	Kangaroo rat	2	4/2	3	19.08	0.86
	Jack rabbit	2	4/2	2	1,348	61.3
	Kangaroo rat	2	4/16	1	938	42.7
	Jack rabbit	2	4/29	1	1,014	46.1
	Kangaroo rat	7	4/26	1	191	8.71
Thyroid	Jack rabbit	2	4/2	6	18,046	821
	Cottontail rabbit	2	4/16	1	2,619	119
	Jack rabbit	2	4/16	4	3,202	146
	Jack rabbit	2	4/29	1	9,258	421
Fetal thyroid	Jack rabbit	2	4/29	1	244	11.1
Thyroid	Kangaroo rat	2	4/29	4	1,458	66.3
	Kangaroo rat	5	4/19	1	32,982	1500
	Ground squirrel	7	4/26	2	28,020	1270
	Kangaroo rat	7	4/26	19	191	8.7
Bladder	Kangaroo rat	2	4/16	4	33.0	1.5
	Kangaroo rat	2	4/16	5	9.96	0.45
	Kangaroo rat	2	4/16	18	3.96	0.18
Spleen	Jack rabbit	2	4/16	4	13.8	0.62
	Kangaroo rat	2	4/16	5	1.56	0.07
	Kangaroo rat	2	4/16	18	1.44	0.06
	Cottontail rabbit	2	4/16	1	10.8	0.49
	Kangaroo rat	5	4/19	1	266	12.1
Kidney	Jack rabbit	2	4/16	4	447	20.3
	Kangaroo rat	2	4/16	4	15.0	0.68
	Kangaroo rat	2	4/16	5	31.0	1.41
	Pocket mouse	2	4/16	1	9.6	0.43
	Kangaroo rat	2	4/16	18	13.9	0.63
	Cottontail rabbit	2	4/16	1	312	14.2
	Pocket mouse	5	4/19	29	581	26.4
	White-footed mouse	5	4/19	8	831	37.8
	Kangaroo rat	5	4/19	1	1,254	57.1
Mammary tissue	Jack rabbit	2	4/16	1	210	9.56
	Jack rabbit	2	4/29	1	1,726	78.5

*All animals were collected from 10 to 20 miles from respective Ground Zeros.

radioactive material in the thyroid. Decay and energy determinations confirm the presence of I^{131} (0.6-Mev beta radiation and 0.38-Mev gamma radiation with a half life of 8.4 days).

The relative fluctuations of the radioactive content in tissue in the population of native rodents sampled from the biological study areas over a period of two years are summarized in Table 3.9. It will be noted in all cases that the residual radiation measured in July 1953 is higher than the natural background values established for jack rabbits in September 1951 prior to known contamination of the areas studied.

[redacted]

Table 3.9—FLUCTUATIONS IN THE AMOUNT OF RADIOACTIVE MATERIAL PER UNIT WEIGHT OF ANIMAL TISSUE AS FUNCTIONS OF TIME AND REPEATED CONTAMINATIONS

Kangaroo Rats, Average Activity, Dis/min/100 mg of Ash

Locality*	Date collected	Lung	GI tract and contents	Liver	Muscle	Bone
I	Oct. 1952	35.2	90.8	38.6	33.2	11.8
	Mar. 1953	15,164	232,988	32,169	13,076	462
	June 1953	39.5	120	42.3	41.7	7.2
II	Oct. 1952	28.4	226	78.5	20.0	25.1
	June 1953	1.93	297.2	52.1	58.3	34.4
III	Oct. 1952	36.5	72	68.3	26.3	11.8
	June 1953	235	92	92	263	22.8
IV	Oct. 1952	19.5	15.1	22.2	7.4	2.4
	June 1953	92.5	68.2	58.9	91.7	23.02

Jack Rabbits, Average Activity, Dis/min/100 mg of Ash

Locality*	Date collected	Lung	Caecum and contents	Liver	Muscle	Bone
Groom Lake and vicinity	Sept. 1951		9.92	11.1	25.0	1.95
I	Oct. 1952	10.9	270	13.1	31.8	19.7
	Mar. 1953	1774	12,455	590	39.3	44.0
	June 1953	48.9	471	28.5	22.7	7.2
II	Oct. 1952	11.7	3,260	78.1	10.4	25.1
	June 1953	38.3	231.6	5,988	28.3	17.6
III	Oct. 1952	11.7	313	12.9	29.1	20.9
	June 1953	32.9	138.4	22.4	25.7	10.1
IV	Oct. 1952					
	June 1953		815	40.9	37.7	5.4

*Refer to Table 3.3 and Fig. 2.1.

3.4 ENVIRONMENTAL CONTAMINATION BY RADIOACTIVE FALL-OUT

The objectives of this project were to determine whether or not enough radioactive fall-out occurred in off-site locations at distances less than 30 miles from Ground Zero to produce significant accumulations in biological systems and to determine what the biological fate and possible effects of radioactive fall-out might be. A comparison of the degree of radioactive contamination of biological sampling areas resulting from primary fall-out of three different detonations of Operation Upshot-Knothole is presented in Table 3.10.

Contamination of the biological sampling station at Nye 1, following Shot 7, represents the extreme condition measured in an off-site area during the participation of Program 27 in Operation Upshot-Knothole.[2] It was also the only location from which detailed physical and biological data were successfully obtained during the same conditions of contamination. Similar data were not available for other detonations because of lack of equipment and inadequate communications. A detailed summary of the physical measurements of radioactive contamination measured at Nye 1 station, in the 24-hr period following Shot 7, is presented in Table 3.11. Since these data represent an extreme condition, they will serve as the main reference in the discussion that follows.

Dosage to internal tissues is largely dependent on the ingestion and/or inhalation and metabolism of radioactive materials. The metabolic availability is dependent on the physical and chemical properties of the fall-out materials.

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Table 3.10—RADIOACTIVE CONTAMINATION OF BIOLOGICAL SAMPLING AREAS BY PRIMARY FALL-OUT FROM SHOTS 2, 5, AND 7

Shot	2	5	7
Distance from Ground Zero, miles	19	31	16
Time of fall-out, min after shot	60	60	40
Activity at time of fall-out, r/hr	5	12	52
Contamination of forage plants, $\mu c/g$ of dried material	0.186		0.45
Surface-soil activity, $\mu c/ft^2$ (H + 12 hr)	1340	9410	18,600

Per Cent of Total Soil Activity Associated with Soil Particles

Particle diameter, μ	Shot 2	Shot 5	Shot 7
2000–833	0.4	0.07	0
833–350	14.6	10.1	0
350–175	80.2	79.2	85.2
175–125	0.5	1.0	5.2
125–88	0.7	1.4	1.9
88–44	1.2	3.6	4.9
44–5	2.4	3.3	2.5
5–0	*	1.3	0.3

*Not determined; included in 44- to 5-μ fraction.

Data from fall-out particles studied by Program 27 may be briefly summarized as indicating a less than 1 per cent solubility of fall-out particles in water and an approximate 2 per cent solubility in 0.1N HCl. Approximately 85 per cent of the radioactivity of primary fall-out is associated with particles 175 to 350 μ in diameter. Approximately 3 per cent of the radioactivity is associated with particles less than 44 μ in diameter. The activities of particles isolated from the fur of exposed animals at H + 12 hr are listed below.

Particle size	Activity, μc
1.2 × 1.4 mm	160
288 μ dia.	14.5
176 μ dia.	4.5
154 μ dia.	3.5

The larger particles are presumably capable of producing burns (Fig. 3.3).

3.5 SUMMARY

1. Radioactive material resulting from fall-out is immediately available to animals at microcurie levels.

2. The highest concentration of radioactive material per organ is found in the gastrointestinal tract. The highest concentration of absorbed and/or metabolized radioactive materials is found in the thyroid and liver.

3. Radioactive materials have been found in all tissues that were assayed, including lung, gastrointestinal tract, liver, muscle, bone, spleen, kidney, thyroid, bladder, fetus, and mammary tissue.

4. The residual radioactive material in tissues of native rodents 100 days after contamination is several times greater than background values obtained in September 1951 but in some cases is lower than reference values obtained in October 1952.

[redacted]

Table 3.11—SUMMARY OF PHYSICAL MEASUREMENTS OF RADIOACTIVE CONTAMINATION OF STATION NYE 1 BY FALL-OUT FROM SHOT 7

Distance from Ground Zero	16 miles
Time of fall-out	H + 40 min
Readings 3 ft from soil surface,	
H + 12 hr	1630 mr/hr
H + 24 hr	700 mr/hr
Gummed-paper activity (beta-gamma), H + 24 hr	1.1×10^4 μc/ft^2
Associated soil activity, H + 12 hr	1.85×10^4 μc/ft^2
Average airborne activity for first 24-hr period after shot*	1.145 μc/m^3
Bearing	108° E of N
Calculated activity at fall-out time	52.2 r/hr
Calculated accumulated 24-hr gamma dose	87 r
Measured accumulated 24-hr dose (film badge)	95 r 237 rems (beta)
Associated plant activity per gram of dried material, H + 12 hr	0.45 μc

Airborne Material Particle Size (Cascade Impactor Sampling at 3 Miles North of Nye 1)

Time after detonation	Mass median diameter, μ	Percentage size distribution > 5 μ	Percentage size distribution > 1 μ
H + 40 min − H + 4 hr	1.75	85	29
H + 8 hr − H + 12 hr	1.15	85	46

Decay Constant of Gross Fission Products as a Function of Sampling Method

Sampling method	Decay constant	
Gummed paper	1.20	Av. 1.23
Soil	1.27	
Low-volume air samplers	1.37	Av. 1.38
High-volume air samplers	1.43	

Measured Energy Components of Fall-out vs Time

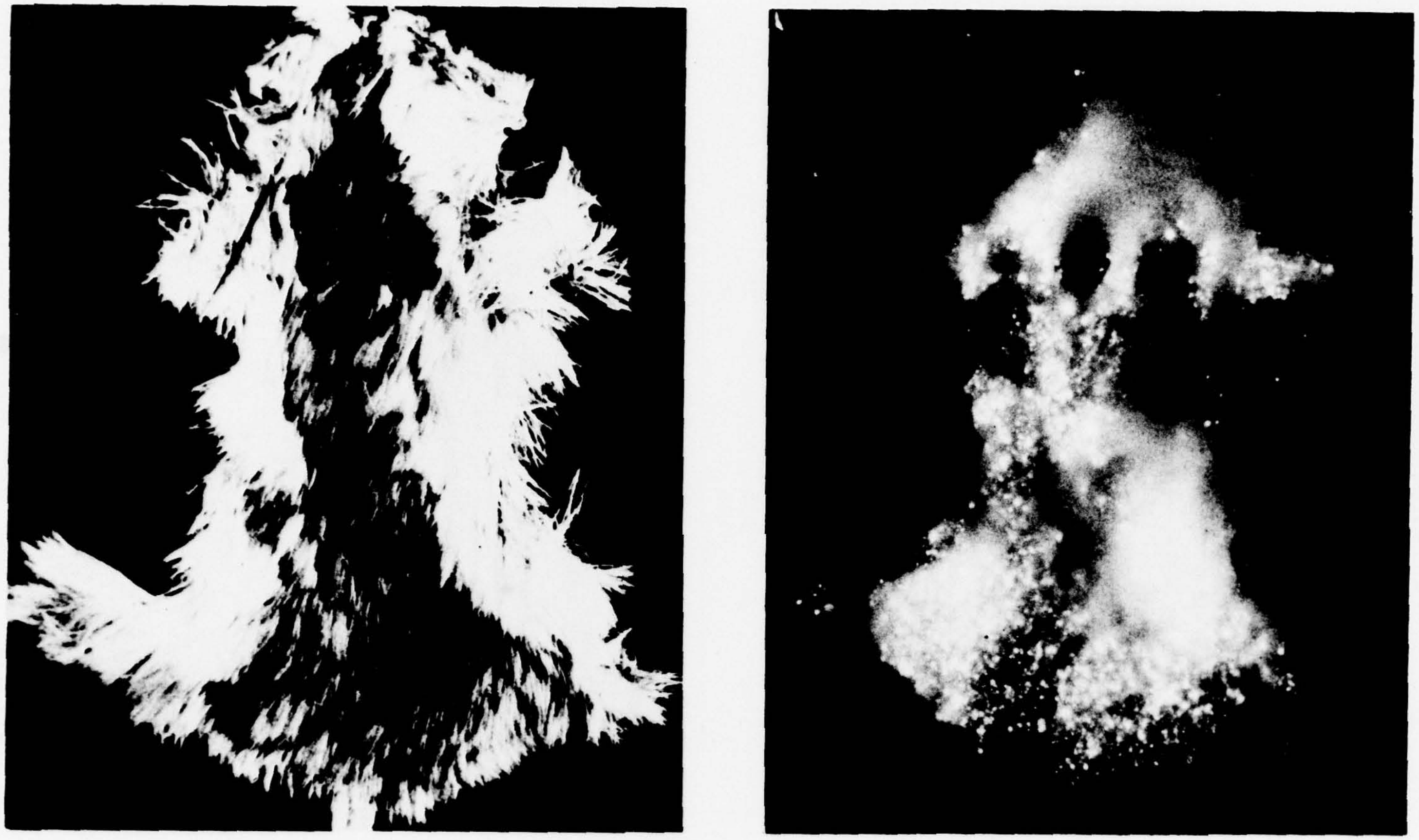
Time after detonation, hr	Energy, Mev	Per cent of measured activity
5	1.346	51.2
	0.247	26.4
	0.029	24.3
	0.749†	
486	0.691	30.4
	0.310	48.4
	0.058	24.0
	0.442†	
2443	1.05	60.8
	0.10	34.9
	‡	4.3
	0.73†	

*See Table 4.1.

†Average effective energy, derived by weighting each component to yield equal per cent of total measured activity.

‡Not detectable.

[redacted]



(a) (b)

Fig. 3.3—Kangaroo-rat pelt contaminated by radioactive fall-out. (a) Dried pelt from a kangaroo rat exposed for 24 hr in the fall-out from Shot 7, 16 miles from Ground Zero. Actual size. (b) An autoradiograph of the same pelt made four days after contamination by fall-out. Thirty-minute exposure on Kodak Type K X-ray Safety film; actual size.

[redacted]

5. The maximum 24-hr dose of external gamma radiation, as measured by chemical dosimeter 6 in. above the ground at Nye 1 station, was 65 r. The maximum internal body dose measured similarly was 20 r.

6. The 24-hr accumulated dose, as measured by film badges exposed 3 ft above ground surface to fall-out contamination from Shot 7, was 95 r and 237 rems.

7. Plant material under the same conditions was contaminated to the degree of 0.45 $\mu c/g$ of dried plant material.

8. Fall-out particles at 16 miles have been isolated from the fur of rodents which contained sufficient activity to probably produce contact radiation burns.

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CHAPTER 4

DISCUSSION

4.1 ENVIRONMENTAL CONTAMINATION BY RADIOACTIVE FALL-OUT

Physical measurements[1-3] of radioactive contamination of the Nye 1 station (16 miles from Ground Zero) suggest that the amount and nature of external radiation, derived from fall-out, are apparently not great enough at this distance to produce an acute effect on animals fully exposed along the midline of fall-out for the 24 hr following Shot 7. An exception to this might be beta-radiation burns resulting from particles lodging in the fur. However, gross pathological changes have not been observed on native rodents.

Gross pathological changes resulting from external radiation may not be expected in native rodents whose secretive habits tend to shield them from significant amounts of radiation. The ingestion and absorption of radioactive materials, however, is high enough to warrant study of more subtle chronic effects which may result from persistent feeding and absorption of "sub-lethal" doses of contamination.

4.2 RADIOACTIVE MATERIAL METABOLICALLY AVAILABLE THROUGH INHALATION

The airborne contamination measured at the midpoint of each of twelve 2-hr sampling periods following Shot 7 is summarized in Table 4.1. The theoretical maximum concentration of absorbed radioactive material which could result in an animal from inhalation of airborne contaminants may be computed by multiplying the airborne concentration of radioactive materials, measured during any sampling period, by the estimated volume of air inhaled by an animal during that time.[4] Two assumptions are made, both of which are improbable but, nevertheless, define the maximum uptake that can be expected under observed conditions. First, it is assumed that 100 per cent of the inhaled radioactive material will be absorbed and retained. Second, it is assumed that the quality and quantity of inhaled contamination is similar or proportional to that determined by air-sampling equipment.

Each value in Table 4.1 has been extrapolated to the time of sacrifice of the experimental animals at H+24 hr. These values (labeled "residual") are the theoretical contributions of each 2-hr sampling period to the total environmental contamination and to the total absorbed radioactive material in the animal.

These calculations reveal that, after 24 hr of exposure at station Nye 1, the maximum residual absorbed and/or metabolized radioactive material that could be expected to result from inhalation is 0.039 μc for a rat, 0.11 μc for a rabbit, and 1.24 μc for a man. Approximately 80 per cent of this value would result from the first 12 hr of exposure.

Reexamination of Table 3.6 indicates that the total residual ingested, inhaled, and absorbed radioactive material measured in a rat after 24 hr of exposure to these conditions is approxi-

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Table 4.1 — MAXIMUM AMOUNT OF RADIOACTIVE MATERIAL THEORETICALLY AVAILABLE TO CAGED ANIMALS AND MAN THROUGH INHALATION AND ABSORPTION OF AIRBORNE FALL-OUT*

Midpoint of sample period, hr after detonation	Measured airborne activity, $\mu c/m^3 \times 10^{-3}$	Calculated residual airborne activity, $\mu c/m^3 \times 10^{-3}$ (H + 24 hr)	Animal uptake,† $\mu c \times 10^{-3}$					
			Rat		Rabbit		Man	
			Inhaled	Residual (H + 24 hr)	Inhaled	Residual (H + 24 hr)	Inhaled	Residual (H + 24 hr)
1	9900	218	495	11	1400	31	15,700	340
3	2360	194	118	9.7	340	27	3,700	310
5	750	113	37.5	5.7	110	16	1,200	180
7	275	62	13.4	3.1	39	8.7	440	98
9	137	42	6.8	2.1	19	5.9	220	66
11	45.8	18	2.29	0.9	6.6	2.5	71	28
13	173	82	8.65	4.1	25	11.0	270	130
15	84.3	48	4.22	2.4	12	6.7	130	76
17	5.95	4.0	0.29	0.20	0.8	0.56	90	6.3
19	1.23	1.0	0.06	0.05	0.17	0.14	19	1.6
21	1.33	1.0	0.06	0.05	0.18	0.14	21	1.6
23	4.60	4.0	0.23	0.20	0.66	0.56	73	6.3
			0.68‡	0.039§	1.97‡	0.11§	21.9‡	1.24§

* Estimates based on data from Nye 1 station, Shot 7.

† Inhalation rates:[4] rat, 0.05 m^3/2 hr; rabbit, 0.14 m^3/2 hr; man 1.58 m^3/2 hr.

‡ Total theoretical exposure in microcuries during 24 hr.

§ Total theoretical metabolic retention in microcuries at end of 24 hr.

mately 0.922 μc compared to a total of 0.039 μc theoretically attributable to inhalation. For rabbits the total residual activity as measured is approximately 6.2 μc compared to a total of 0.11 μc attributable to inhalation.

A more realistic evaluation of metabolic availability of inhaled radioactive material may be to compare the total inhaled contamination only to the amount of radioactive material actually absorbed and/or metabolized. For the rat, absorbed activity is six times greater than the theoretical inhaled contamination, and, for the rabbit, absorbed activity is twenty times greater. A conservative statement is that some absorbed radioactive material may be attributable to inhalation, but inhalation fails to account for the bulk of absorbed radioactive contamination.

If the residual radioactive material in the lung at H + 24 hr (Table 3.6) is compared with the expected inhalation of contaminants during the air-sampling period from H + 22 hr to H + 24 hr, it will be noted that there is some indication of retention of radioactive material in the lung. The contamination in the lungs of both kangaroo rats and domestic rabbits is approximately 100 times greater than that which would be predicted to result from the single 2-hr exposure.

For the kangaroo rat the retained radioactive material in the lung is 0.6 per cent of the total uptake that could be expected to result from inhalation during the 24-hr exposure as compared to 11 per cent for the Dutch rabbit. These differences can be accounted for in terms of differences in pulmonary clearance rates and air flows between the two animals.

These data further indicate that a maximum activity of 15.7 μc could be taken into the respiratory passages of a man located at Nye 1 during the first 2 hr following the detonation. If it is assumed that this material has an average energy of 0.75 Mev and is uniformly distributed through the lungs (average wet weight, 242 g), it would result in a total dosage of 0.2 rep for the 2-hr period or less than 1 rep for the combined dose of all 12 sampling periods. Although the majority of sampling data indicate that these assumptions are valid, there are also sampling data to indicate that this amount of radiation could be concentrated in a single particle of inhalable size, in which case the local rep dose to immediate tissue may be several orders of magnitude greater.

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4.3 RADIOACTIVE MATERIAL BIOLOGICALLY AVAILABLE THROUGH INGESTION

A rabbit feeding at a normal rate on plant material contaminated at the measured rate of 0.45 μc/g of dried plant material would, in the 24 hr following the detonation, consume approximately 225 g of plant material and an associated 101 μc of radioactive material. If it is assumed that the solubility of this contamination is the same as that established for individual particles in the laboratory, it can be assumed that 2 per cent of the ingested material will be soluble in gastric juice and be available for absorption from the gastrointestinal tract. Thus it would be expected that up to 2.02 μc of ingested fission products could be absorbed. The average measured absorbed activity of four caged rabbits exposed under these conditions was approximately 2.24 μc.

A kangaroo rat, feeding under the same conditions, would consume 4.5 μc, of which 0.09 μc would be available for absorption. The average absorbed activity measured in four exposed rats was approximately 0.25 μc.

The total radioactive material concentrated in the surface layers of soil at H + 12 hr was 18,600 $\mu c/ft^2$, or, assuming a 2 per cent solubility, 372 $\mu c/ft^2$ of radiation potentially available for absorption. It becomes obvious that the total contamination ingested and/or absorbed is only a trace of the total radioactive material to which the animal is exposed. The close agreement of predicted and measured metabolic activity is surprising indeed since it is known that the animals failed to consume their normal daily ration. One should expect large variations in uptake because of the large amount of contamination in the area and because of such animal behavior as licking of fur, spilling of food, and dusting.

Another large variable is the solubility of fall-out materials. Although a 2 per cent solubility of fused fall-out particles is probably valid as an average value of the few that have been studied, several calcareous particles have been investigated which have solubilities as high as 75 per cent in 0.1N HCl.

It has been assumed that the size of the particle may determine its potential metabolic availability. Examination of primary fall-out particles from Shots 5 and 7 reveals that the particles from Shot 5, sampled 31 miles from Ground Zero, are, on the whole, slightly larger than the particles sampled from Shot 7 only 16 miles from Ground Zero (Table 3.10). Activity at the time of fall-out was calculated to be 12 r/hr at the Shot 5 sampling area and 52.2 r/hr at the Shot 7 sampling area. Despite these differences it will be noted that the animals sampled after Shot 5 were ten to thirty times more contaminated than the animals sampled after Shot 7 (Tables 3.5 and 3.6). This suggests an inverse relation between the degree of environmental contamination and biological uptake, which in turn infers relatively greater metabolic availability of radioactive fall-out with distance.

It is possible that the fused siliceous particles, which have received some emphasis in study, in themselves contribute the least to metabolic activity. The major contribution as previously suggested[5] could logically come from more soluble radioactive material adsorbed to primary fall-out materials. It would appear, therefore, that metabolized radioactivity in animals may be essentially independent of particle size and total environmental contamination and dependent on a specific fraction of total fall-out of a more soluble nature which will be produced in variable quantities as a function of the type of detonation, the soil properties at Ground Zero, and general meteorological conditions.

4.4 FATE OF ABSORBED RADIOACTIVE MATERIALS

Figures 4.1 and 4.2 are examples of typical radioactive decay in tissues from kangaroo rats and jack rabbits contaminated by Operation Upshot-Knothole. It will be noted that the slopes are similar for each type of tissue. Thus the radioactive decay in the liver of the kangaroo rat and the liver of the jack rabbit are similar and have characteristic slopes different from the femur, muscle, etc. The decay slope of the gastrointestinal tract and lung are almost parallel to the theoretical gross fission product decay as would be expected. The liver, muscle, and bone, however, have slopes which suggest that the ingested or inhaled gross fission

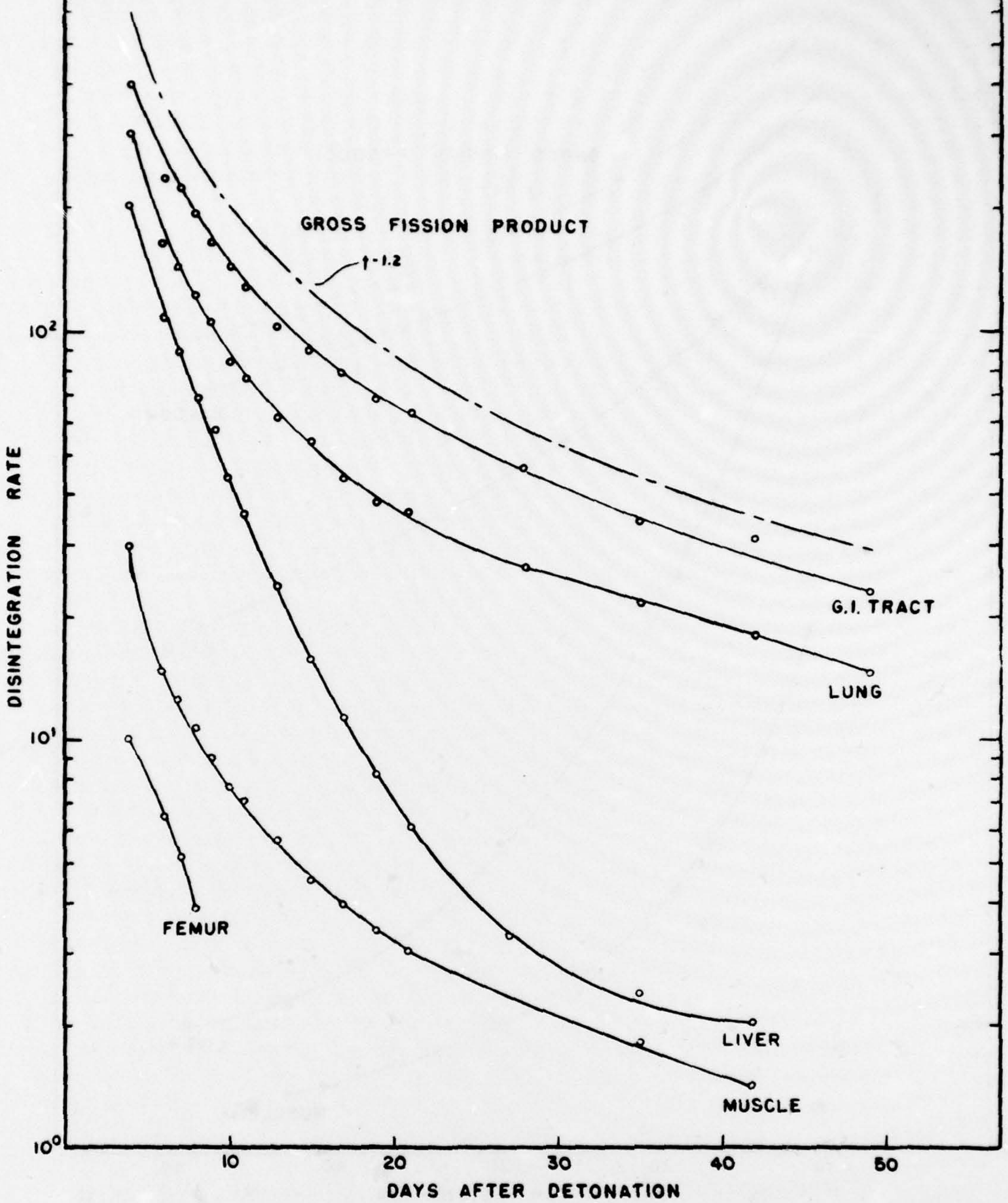

Fig. 4.1—Relative decay of radioactive material in tissues from kangaroo rats contaminated by Operation Upshot-Knothole.

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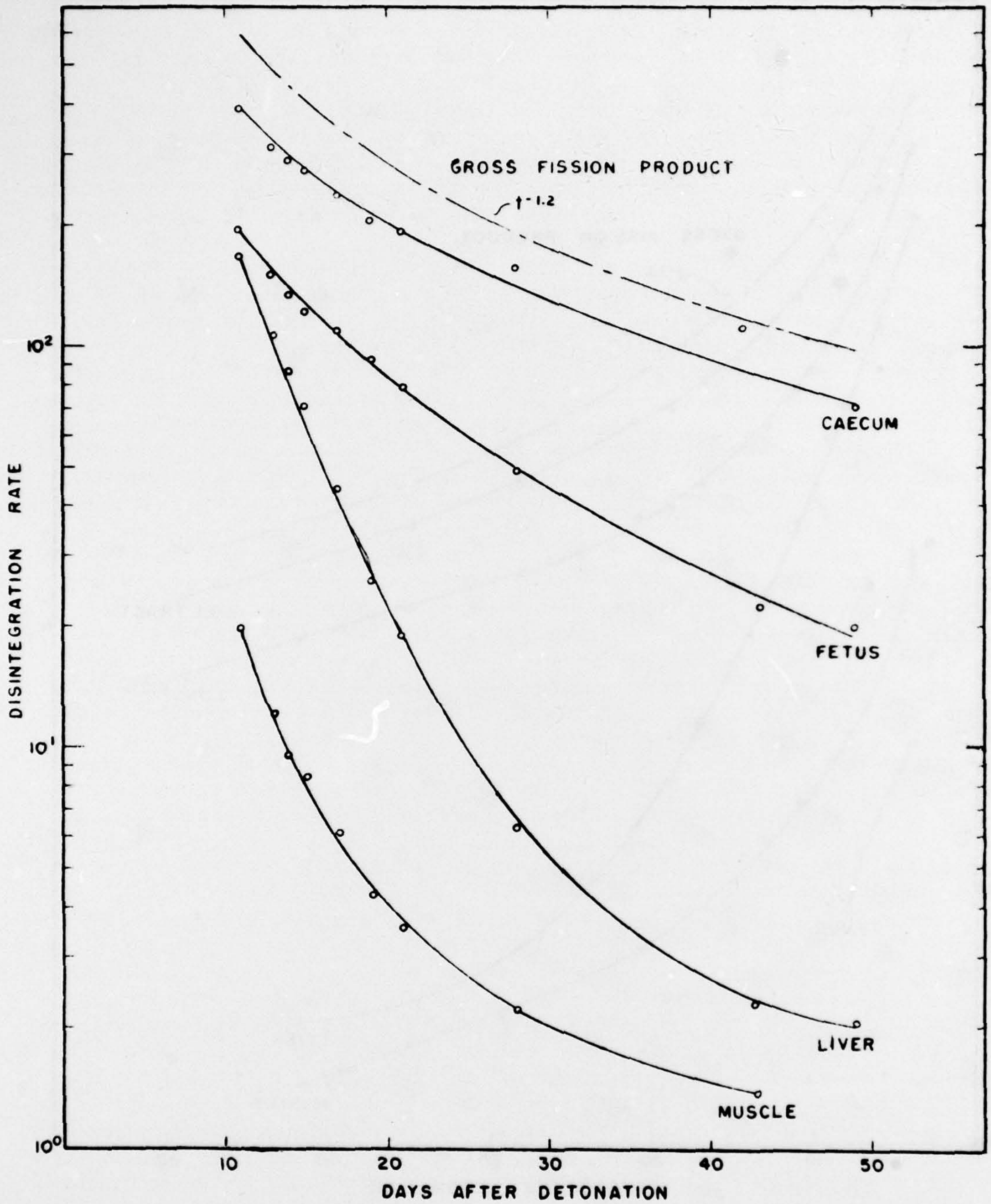

Fig. 4.2—Relative decay of radioactive material in tissues from jack rabbits contaminated by Operation Upshot-Knothole.

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contamination has been metabolically fractionated. This is evidence that the measured activity is the result of absorbed materials and not of contamination from external sources during autopsy.

Attempts to identify the specific radioisotopes in tissues have been relatively unsuccessful. Standard methods of half-life and energy determinations reveal that the radioactive material apparently consists of several fission products of similar energies and half lives.

Detailed analysis of Figs. 4.1 and 4.2 suggests that the radiation measured during the first few days after absorption is due largely to a predominant isotope common to all tissues. The decay rates of different tissues diverge with time, presumably reflecting differential concentrations of the isotopes present. It may be conservatively stated that the radioactive decays, as plotted, strongly suggest the presence of one (or a few) isotope which dominates the over-all decay scheme.

During the first week after the contaminating detonation, the absorbed radioactive material is characterized by a resultant half life of 65 to 72 hr and a resultant beta energy of 1.2 to 1.5 Mev. After about two weeks the resultant half life has changed to about 15 to 18 days. The energies have not changed significantly.

One jack rabbit was collected approximately 20 miles north northeast of Shot 2 Ground Zero on Apr. 2, 1953. Analysis of the thyroid produced 98,060 dis/min per organ. The presence of I^{131} was confirmed by energy and half-life determinations. This activity extrapolated to the time of collection is equivalent to approximately 0.21 μc/g of thyroid tissue or 16.1 reps/week.*

In an attempt to identify the isotopes contaminating the bone, the ash of four jack-rabbit femurs that still showed significant activity five months after contamination were combined and the alkaline-earth elements extracted by the nitric acid–calcium oxylate method.[2] All the activity was present in the precipitate. No activity was detected in the filtrate. Although further fractionations and identifications were not possible with the techniques available at the time, these results do suggest at least two possible fission products, strontium and barium, accumulating in the bone. However, because of various factors (such as the periodic contamination of the environment by annual test series, the nature of the tissue decay curves, and the life span of the animals), it would appear premature to attribute increases in tissue activities only to long-lived isotopes rather than recontamination by short half-lived fission products.

The Shot 2 animal data indicate an interesting distribution of metabolic activity as a function of time (Tables 3.3 and 3.4). In terms of activity per organ the liver has about 80 per cent of the metabolized activity at D+1 sampling as compared to 2.4 per cent for the femur.

Ninety-six days later the per cent activity is roughly equal in the two tissues. This suggests a deposition or retention of activity in the bone as compared to the highly mobile condition of the activity in the liver, the amount of which appears to be largely dependent on the concentration in the gastrointestinal tract.

A comparison of three types of decay curves resulting from samples contaminated by Shot 2 is given in Figs. 4.3 to 4.6. The gross fission decay plotted according to the $t^{-1.2}$ decay constant is presented for reference. The tissue activity represents the average activity per unit weight (disintegrations per minute per 100 mg of ash) in liver and femur samples obtained 1, 9, 23, 38, and 96 days after detonation from the natural population living in the contaminated environment. The tissue decays are plots of individual samples obtained during the same period. It will be noted that, in the case of both the kangaroo-rat liver and the jack-rabbit liver, the tissue decay closely follows the curve representing activities in the livers of animals periodically sampled from the population. In the case of the femur this relation is not as apparent.

These curves suggest either that these animals were initially contaminated during the first week of exposure and the resulting tissue decay represents decay of this original contamination or that the activity in the liver is at equilibrium with the environment, so that a lower concentration in the environment will result in a lower concentration in the liver. The latter explanation is to be preferred since the habits of the animals are such that it is almost inconceivable

* Calculations made by K. Herde of Savannah River Operations Office while participating in activities of Program 27.

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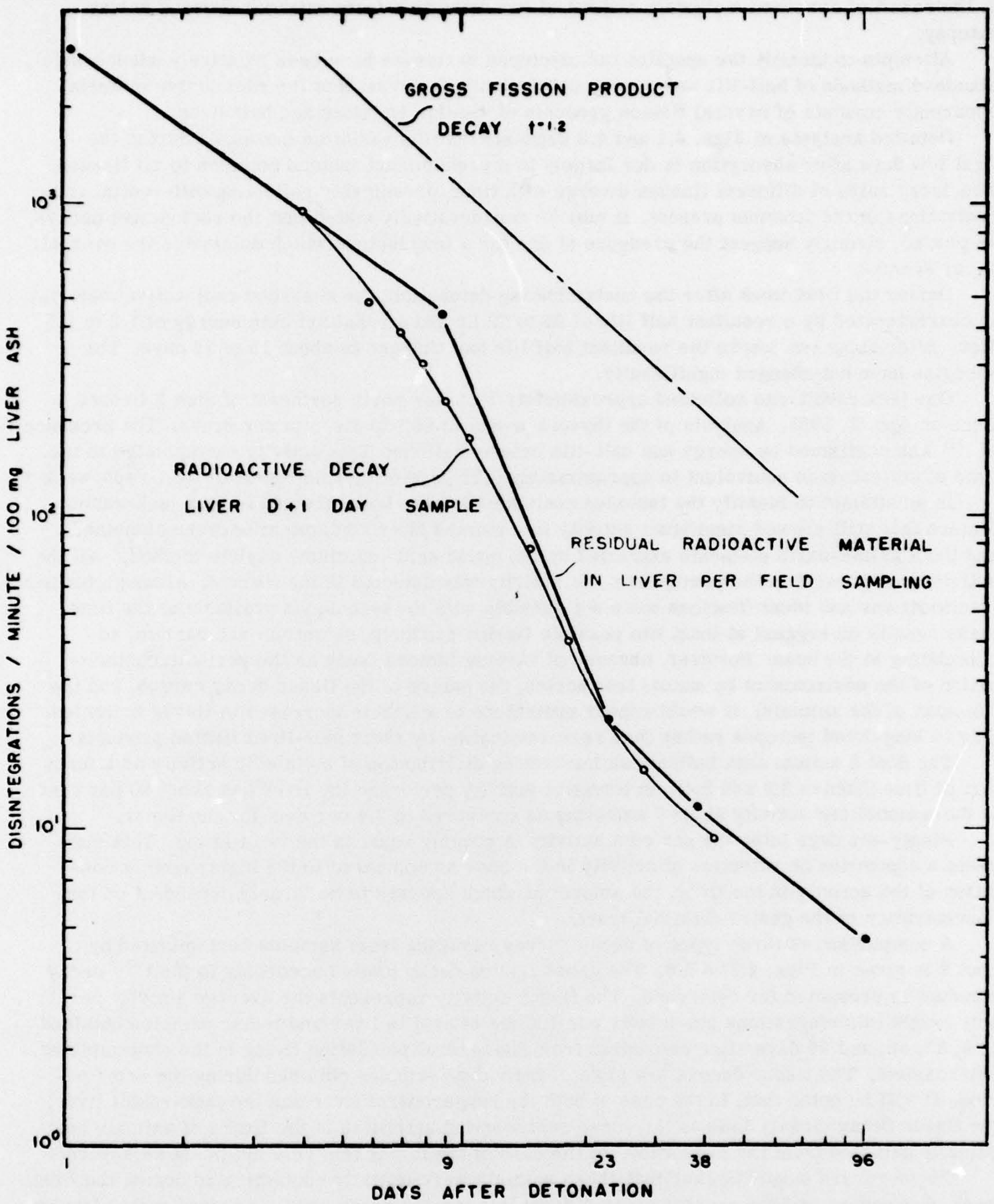

Fig. 4.3—Comparison of the relative radioactive decay of gross fission products to the decay of radioactive material in a sample of kangaroo-rat liver and to the average residual radioactive material in kangaroo-rat livers serially sampled from the natural population contaminated by Shot 2.

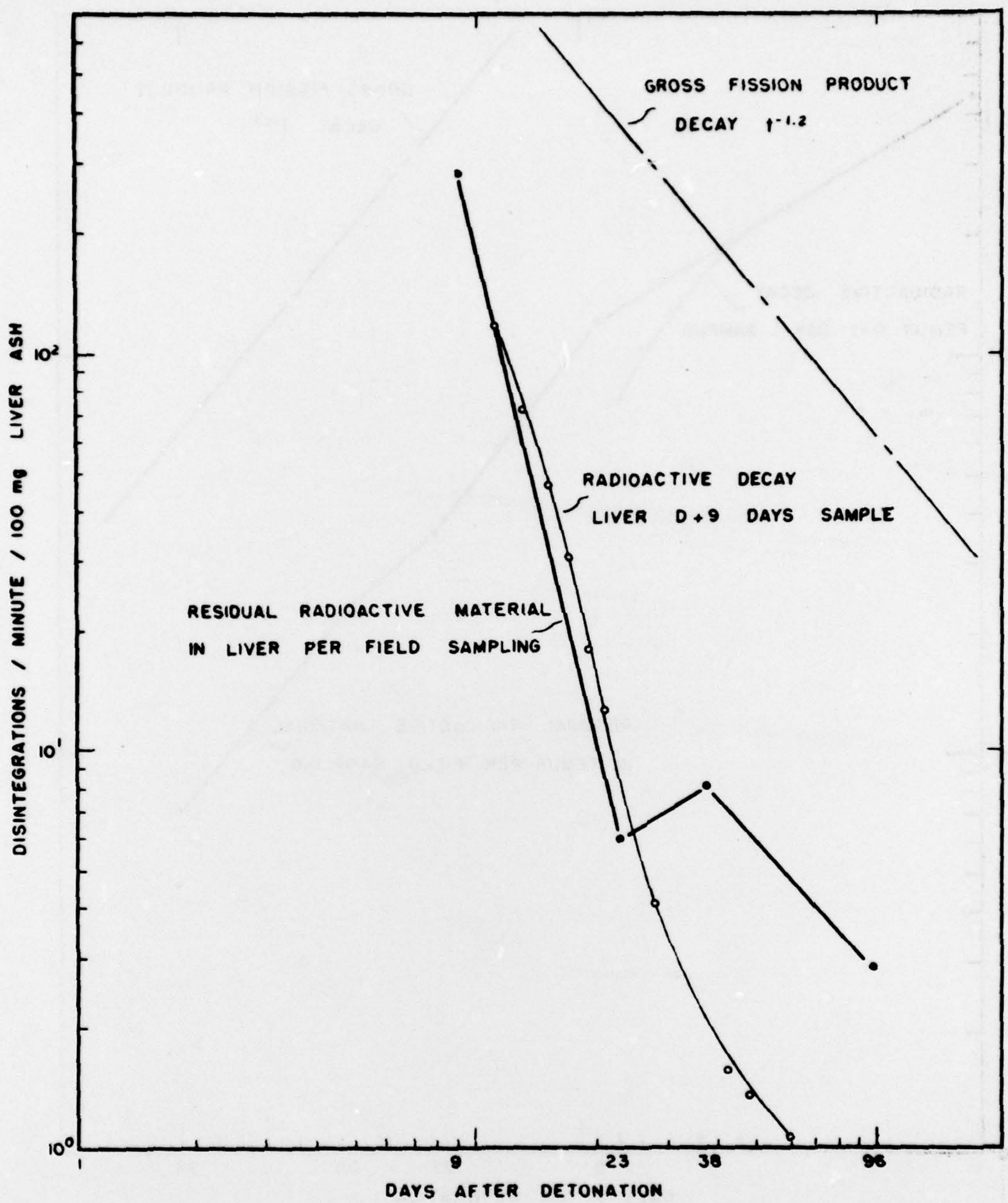

Fig. 4.4—Comparison of the relative radioactive decay of gross fission products to the decay of radioactive material in a sample of jack-rabbit liver and to the average residual radioactive material in jack-rabbit livers serially sampled from the natural population contaminated by Shot 2.

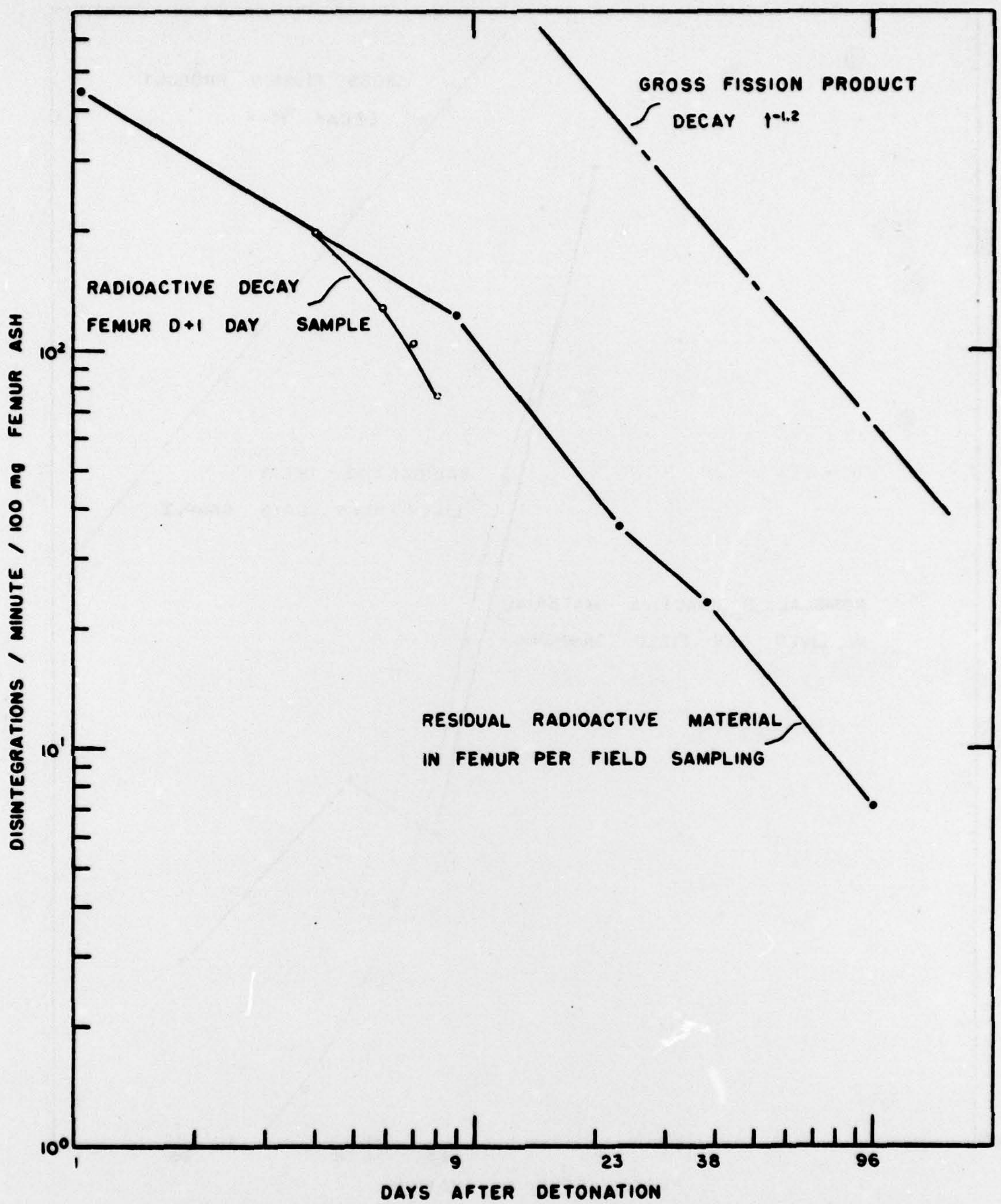

Fig. 4.5—Comparison of the relative radioactive decay of gross fission products to the decay of radioactive material in a sample of kangaroo-rat femur and to the average residual radioactive material in kangaroo-rat femurs serially sampled from the natural population contaminated by Shot 2.

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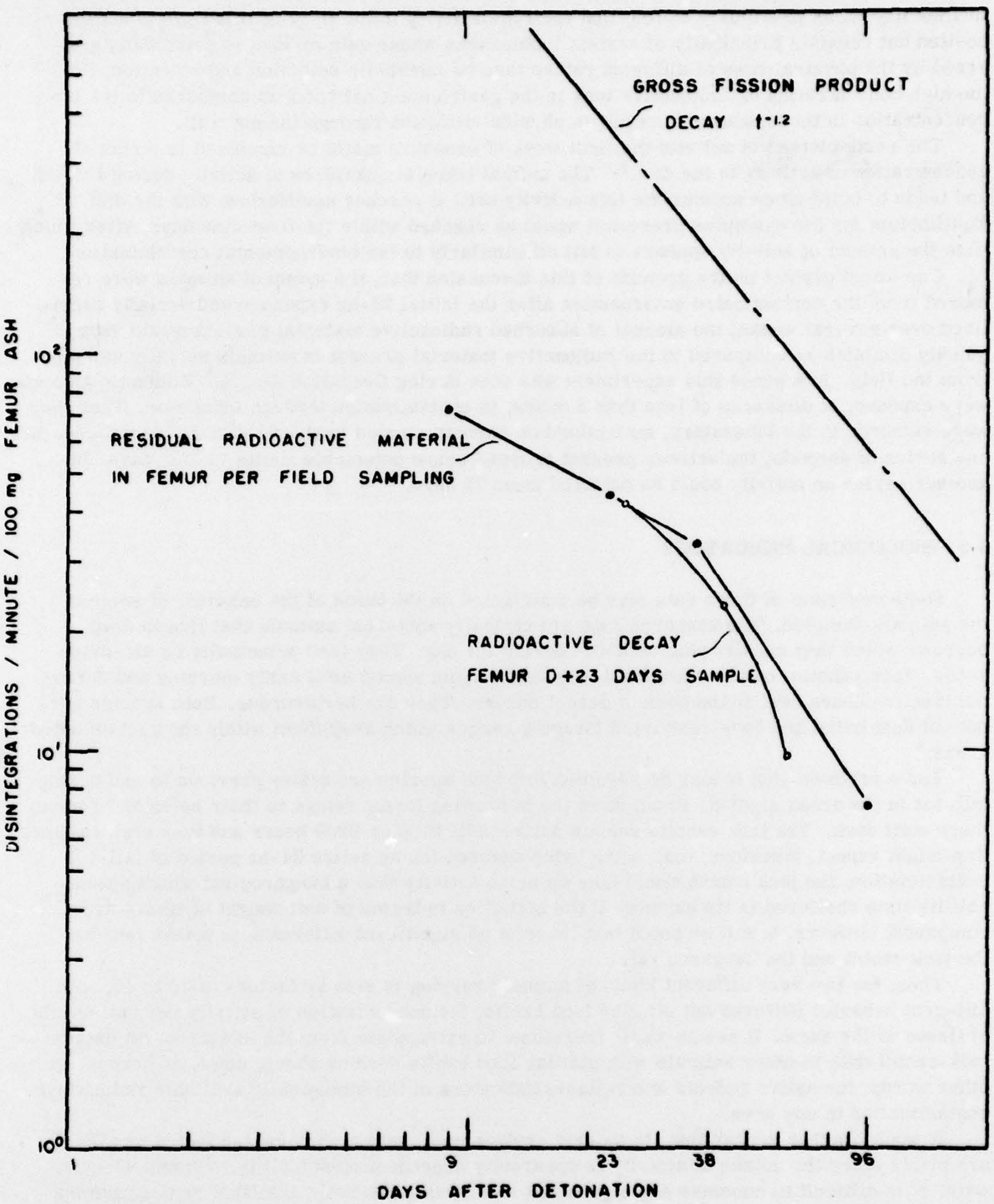

Fig. 4.6—Comparison of the relative radioactive decay of gross fission products to the decay of radioactive material in a sample of jack-rabbit femur and to the average residual radioactive material in jack-rabbit femurs serially sampled from the natural population contaminated by Shot 2.

[redacted]

that they would not become recontaminated (if available material is present). This explanation further infers, as previously stated, that the radioactivity in the liver at this time is not deposited but consists principally of certain mobile ions whose gain or loss is principally governed by the physical laws of diffusion rather than by metabolic selection and retention, i.e., the high concentration of radioactive ions in the gastrointestinal tract as compared to the low concentration in the tissues will result in physical diffusion through the gut wall.

The semi-plateau of activity the first week of exposure might be explained in terms of concentration of activity in the diet.[6,7] The animal takes in quantities of activity during feeding and tends to build up or accumulate this activity until it reaches equilibrium with the diet. Equilibrium for the examples presented would be reached within the first nine days, after which time the amount of activity appears to fall off similarly to the environmental contamination.

One would predict on the grounds of this discussion that, if a group of animals were removed from the contaminated environment after the initial 24-hr exposure and serially sacrificed over several weeks, the amount of absorbed radioactive material present would very quickly diminish as compared to the radioactive material present in animals serially sampled from the field. In a sense this experiment was done during Operation Jangle.[5] Domestic animals were exposed, at distances of less than 5 miles, to contamination through inhalation. Then they were removed to the laboratory, maintained on uncontaminated food, and serially sacrificed. In one series of animals, the activity present dropped below detectable limits in four days. In another series no activity could be detected after 75 days.

4.5 BIOLOGICAL INDICATORS

Some criticism of these data may be anticipated on the basis of the behavior of some of the animals sampled. The kangaroo rats are typically nocturnal animals that live in deep burrows which they usually plug with dirt during the day. They feed principally on air-dried seeds. Jack rabbits, on the other hand, are active from sunset until early morning and during the inactive hours rest at the base of desert shrubs. They are herbiverous. Both species partake of dust baths and have restricted foraging ranges which keep them within the contaminated areas.[8]

For a predawn shot it may be assumed that both species are active previous to and during fall-out in the areas studied. About dawn the burrowing forms return to their holes and remain there until dark. The jack rabbits remain active until 0700 or 0800 hours and then seek shelter. One might expect, therefore, that, after being exposed for an entire 24-hr period of fall-out contamination, the jack rabbit would take up more activity than a kangaroo rat which spends half its time sheltered in its burrow. If the activities in terms of unit weight of tissue are compared, however, it will be noted that there is no significant difference in uptake between the jack rabbit and the kangaroo rat.

Thus, for two very different kinds of animals varying in size by factors of 30 to 40, with different behavior patterns but similar food habits, the concentration of activity per unit weight of tissue is the same. It seems valid, therefore, to extrapolate from the kangaroo-rat data or jack-rabbit data to other animals with similar food habits such as sheep, cows, or horses. In other words, the native rodents are reliable indicators of the biologically available radioactive contamination in any area.

It would further appear that, in an arid environment, animals are better indicators than are plants since the uptake of activity is apparently dependent on solubility. Without adequate water it is difficult to conceive any significant amount of potentially available radioactive material being taken up by plants through either the roots or aerial portions. Furthermore, since migration of activity through the soil seems to be a chemical exchange or displacement phenomenon, it would take relatively heavy rainfall or irrigation soon after fall-out to leach the activity down to approximately 2 in. to the "feeder" root zone of plants. These assumptions seem borne out by field data.

Of interest is the observation that the values measured in the tissues of kangaroo rats sampled 96 days after the Shot 2 contamination are in some cases lower than the values meas-

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ured in October 1952, approximately 120 days after contamination by Operation Snapper. This suggests at least two possibilities:

1. Contamination by Operation Snapper may have been more persistent than the contamination by Shot 2 of Operation Upshot-Knothole so that tissue activities were still declining in October.

2. The population sampled during Operation Upshot-Knothole may have been significantly different from that in October due to the occurrence of new offspring. The native rodents have relatively short life spans. The density of the population in October was approximately one-third the population sampled in March. Whether or not radiation contributed to this difference remains to be determined.

4.6 RECOMMENDATIONS

Biological surveys of test sites in New Mexico, the Pacific, and Nevada clearly establish the biological availability of radioactive fall-out. Thus far, gross pathological changes resulting from maximum permissible body burdens of radioactive contaminants have not been noted in the field. Nevertheless, if the fundamental assumption of radiation biology is valid, namely, that radiation is a phenomenon that is destructive to biological systems, then the establishment of biological availability dictates the need of detailed study pertaining to (1) the biological effects of chronic "sub-lethal" dosages of radioactive material and (2) the modifications of biological availability of radioactive materials by the environment.

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CHAPTER 5

SUMMARY

A radiological survey of the area adjacent to NPG was made from September 1951 through July 1953. Samples were taken periodically of the native soils, plants, and animals repeatedly contaminated by fall-out from nuclear detonations.

Data suggest that, at the end of a two-year period, approximately 90 per cent of radioactive contamination on soil in an arid environment remains in the surface inch of soil.

Metabolic activity in plants as estimated by washed material in July 1953 is approximately twice the activity measured in 1951 prior to any contamination. The amount of external contamination on plants may be several orders of magnitude greater.

Metabolic activity in the livers and femurs of jack rabbits sampled in July 1953 is three times greater than the 1951 values. Metabolic activity in animals appears to be in equilibrium with the environment, suggesting that metabolic uptake may result from physical diffusion from the high concentration of radioactive material in the gastrointestinal tract rather than from metabolic selection and retention.

Measurement of radioactive contamination of the environment by Shot 7 in April 1953 was made by Project 27.1. The Nye 1 station, 16 miles from Ground Zero, received 2.57×10^4 $\mu c/ft^2$ by H + 12 hr with a 24-hr gamma dose of 95 r. Approximately 80 per cent of the primary fall-out was associated with soil particles 175 to 350 μ in diameter. With the possible exception of beta burns from individual particles, external radiation was not great enough to produce apparent acute effects on plants and animals.

This degree of contamination resulted in a total metabolic uptake of 2 to 3 μc of radioactive materials by domestic rabbits exposed for the 24-hr period. Plant material was contaminated up to 0.45 $\mu c/g$ of dried plant material at H + 12 hr.

Measurement of airborne concentration of radioactive material and calculations of theoretical maxima of inhaled radioactive materials by different size animals fail to account for the bulk of metabolic radioactivity. Metabolic radioactivity is more completely accounted for through ingestion of primary fall-out.

Except for the confirmation of I^{131} in the thyroid, the identification of contaminating isotopes has been unsuccessful. Decay and energy determinations on tissues suggest the presence of relatively few mixed beta emitters common to all tissues, but varying in their relative concentrations.

Evidence suggests that native rodents are reliable indicators of the biologically available radioactive materials in any area. Changes in the population density of native animals may reflect an effect of repeated radioactive contamination to the environment by fall-out.

Recommendations are made on the basis of biological availability of radioactive fall-out for studies pertaining to (1) the biological effect of chronic "sub-lethal" dosages of radioactive material and (2) the modifications of biological availability of radioactive material by the environment.

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